A study of factors that lead to stress in pigs during road transport including an examination of a novel mechanical ventilation system.

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Abstract

It was proposed that pigs arriving dead at an abattoir, or dying soon after arrival, had suffered from heat-stress during transport by road. A pre-study report showed that the majority of the pigs that had died had been penned on the bottom decks of the truck and trailer units, with the greatest number having been penned in the bottom front pen of the truck crate. Consequently, temperature and humidity within a stock-truck, that transported pigs to an abattoir from two farms, were monitored over a three-year period. A video camera was mounted in the bottom front pen to establish the behaviour of the pigs that were being transported. The videos produced, were then used to establish the point at which open-mouth breathing (an indicator for stress) commenced, and whether this coincided with temperature/humidity index values in the pens. As a qualitative measure of transport stress, meat quality from pigs at different locations on the stock-truck were measured and compared with results from a third 'low-stress' farm. A novel fan-driven ventilation system was designed and installed, and its impact was measured after insulation had been applied to the front wall of the stock-crate. The stock-vehicle design and the ventilation systems used in international stock transport studies, were compared with stock-transport vehicles used in New Zealand, and potential differences in the results from international studies with the current study were discussed. Despite the differences in vehicle designs, the current study suggested that the temperature and temperature/humidity index levels recorded would underpin the onset of heat-stress, particularly during the summer months in New Zealand. Unlike many international studies, evidence of conditions that would lead to substantial cold-stress was not found.

Key words: pigs, temperature/humidity index, transport stress, meat quality, fans

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Chapter one

INTRODUCTION

Rationale for the study

In New Zealand, sporadic deaths occur during the transportation of livestock by road. Records taken over a three-year period (2008-2011) by a New Zealand abattoir, indicated that approximately 17 pigs per 10,000 transported to the abattoir, either arrived dead (DOA), or died soon after entering the abattoir's lairage yards (DIY). Internationally, similar death rates have been reported in the literature (Zurbrigg *et al.*, 2017; Averos *et al.*, 2008; Haley, *et al.*, 2008b; Werner *et al.*, 2007).

Inherently, the transportation of livestock involves a wide range of stressors. Marchant-Forde & Marchant-Forde (2009), in Chapter 10 of their book 'The Welfare of Pigs', broke the stress-related periods during the transport process into loading, transport, stationary period, unloading and lairage. They further separated the stresses associated with loading into the type of housing that the pigs had been reared in, the degree and type of handling that they had experienced prior to transport and the method of loading. They then broke the stresses associated with transport into some of the elements of vehicle design, stocking density and distance travelled. Stationary periods, in their presentation, were taken as those that occurred during the unloading process. In their section on unloading they identified a number of stress-factors that were common to both loading and unloading and in their section on lairage they identified concerns related to the lairage design, length of time before slaughter and the competence of the staff.

The wider research literature confirms that the transport of pigs is a stressful event. A wide range of stressors combine and interact from the time the pigs leave the environment to which they had become habituated, to the time they are killed. Despite the wide range of variables during the transport of animals, heat-stress has been identified as the principal contributing factor by authors investigating the cause of transport deaths (Averos *et al*., 2008; Lenkaitis *et al*., 2007; Ellis & Ritter, 2005).

In New Zealand the Ministry for Primary Industries requires the farmer and truck driver to monitor livestock for their fitness to travel at the time of loading. However, various factors, such as breed and genetics, animal health (particularly sub-clinical disease conditions affecting pigs' lungs), driver behaviour, distance to be travelled, stocking densities, weather patterns, season, the time of day, road conditions, the timing of the animals' last feed, and stock-crate design, have all been found to contribute to stressful conditions for the stock being transported (Peeters *et al.*, 2008; Becerril-Herrera *et al*., 2007; Vecerek *et al.*, 2006; Benjamin, 2005). Variations in published results may well be due to the absence or presence and intensity of the various stressors (Hamilton *et al.*, 2004).

The finding that pigs are more sensitive to high environmental temperatures when compared with other species of farm animals (Curtis, 1983) and their response to heat-stress by commencing open-mouth breathing (Benjamin, 2005), make them an ideal subject for heat-stress studies.

According to American comfort standards, thermal comfort is defined as '*that condition of mind which expresses satisfaction with the thermal environment';* hence, comfort is a subjective sensation (Epstein & Moran, 2006). According to Nielsen *et al*. (2010) and Bouchama & Knochel, (2002) there are no exact threshold values separating normal stress responses from the reduced welfare of an animal. However, it is self-evident that where conditions are severe enough to cause an animal to die during transport, then those conditions may also have led to some degree of suffering before death (Nielsen *et al.*, 2010). It can also be expected that cohort animals in the same environment, that did not die, may have suffered from severe stress as well. Not only will the welfare of the survivors have been compromised but the quality of the meat that they produce may have been affected as well.

Stock transport in the Northern Hemisphere, where most of the studies have been conducted, differs marked from stock transport in New Zealand. No studies on transport stress in pigs have been conducted in New Zealand though two studies (Fisher *et al*., 2002 & 2004) looked at stress (in sheep) during periods when a loaded stock-truck was stationary or travelled on the Cook Strait ferry.

Climate, the type of vehicles used and the stock themselves all differ to such an extent that it was considered important that a study should be mounted in New Zealand to evaluate what factors contributed to DOA and DIY pigs, and what might be done to reduce the problem. As a consequence of concern for the welfare of animals being transported, and the impact that transport-stress may have on meat quality, this study was undertaken to examine the effect of the stock-crate design and the crate environment, and hence the cumulative stresses on pigs during road transport, with the aim of identifying any changes that could be made to improve the conditions for pigs being transported.

The international incidence of pigs that were found dead on arrival or died in the lairage yards after road transport.

Data sourced from overseas research can be difficult to relate to New Zealand transport conditions because of the differences in climate and weather patterns, differences in topography, differences in farming practices, differences in the genetics, size and gender of the pigs used in the studies and the differences in the design and configuration of the transport vehicles that have been used.

In a review of transport practices and mortalities in Australia (APL Project 2010/1021.340, November 2012), Willis *et al.,* (2012), reported a death rate amongst pigs sent to the abattoir of 0.036% over a twelve-month period (May 2011 to June 2012). Ritter *et al.* (2009) cite a number of authors who state that the total pre-slaughter deaths (during transport and in lairage) was 0.12% in Canada (Haley *et al*., 2008a), 0.017% in Denmark (Barton-Gade *et al.*, 1998-2002), 0.085% in Germany (Werner *et al.*, 2003), 0.16% in the Netherlands (Christensen & Deitemeyer, 1993) and 0.05% in the United Kingdom (Riches *et al.*, 1996). Using condemnation data supplied by the United States Department of Agriculture to analyse transport deaths, Peterson *et al.*, (2017) reported that 0.22% of all swine classes transported in the USA between 2000 and 2006 either died, or became non-ambulatory, during transport. As a corollary to the Ritter *et al.,* (2009) sources, Peterson noted that from June to August 2003 (summer months), in Eastern Canada, the incidence of market pig deaths in transit was 0.22%.

Whilst the numbers of pigs that die in transit or die in the lairage before slaughter are modest, the economic impact to the pig industries in each country is significant (Peterson *et al*., 2017; Fitzgerald *et al*., 2009; Ritter *et al*., 2009; Ellis & Ritter, 2005) and the animal welfare compromise is becoming increasingly important to consumers (Loeb, 2018; Schwartzkopf-Genswein *et al*., 2012).

The road transport of pigs and other animal species

Pigs, sheep, cattle, goats and horses have different comfort zones and the upper and lower critical temperatures (the environmental temperatures beyond which animals can no longer maintain a stable core temperature without external heat dissipation or input) of each species are different (Epstein & Moran, 2006). These factors and other inter-species variables lead to different transport requirements for the different species (EEC, STANDARDS FOR THE MICROCLIMATE INSIDE ANIMAL TRANSPORT ROAD VEHICLES, 1999). The EEC report states that animals can cope better at temperatures lower than the lower critical temperatures than they can at temperatures higher than the upper critical temperatures.

A significant amount of transport amongst ruminant species in New Zealand involves such variables as age, weight, height, temperament, genotype, length of wool, distance travelled, stocking densities and season, and involves a wide range of transport operators using diverse stock-crate designs. Ruminants in New Zealand are more often transported on an irregular timetable between farms around the country, often over considerable distances. However, pigs, apart from small numbers of breeding stock that are transported from breeding farms to commercial piggeries, are transported on a regular weekly basis to abattoirs that are generally close to the piggery of origin. Multi-site pig production systems, as are common in Northern Hemisphere countries, where newly weaned pigs are moved to a geographically isolated site requiring the transport of very young and small pigs, is rare in New Zealand. Compared with examining transport stresses amongst ruminant species, pigs have the advantage that the major piggeries produce similar numbers of animals of similar weights, that are sent for slaughter using the same transport operator on a regular weekly routine.

The impact of heat as a stressor during livestock transport

<u>*Heat-stress and heat-stroke*</u>: Heat-stress occurs when the core body temperature of an animal is elevated. It is considered to exist whenever, despite vasomotor adjustments, metabolic heat production exceeds the combined losses by radiation and convection (Bouchama & Knochel, 2002).

In heat-stress, a rise in the temperature of the blood by less than one degree centigrade activates peripheral and hypothalamic heat receptors that signal the hypothalamic thermoregulatory centre. The efferent response from this centre increases the delivery of heated blood to the surface of the body (Bouchama & Knochel, 2002). Active sympathetic cutaneous vasodilation, then increases blood flow to the skin, and initiates thermal sweating. If the air surrounding the surface of the body is not saturated with water, then the sweat will vaporise, and this will cool the body surface (‘evaporative cooling’).

When heated, the mammalian body also responds by repositioning the blood volume from the abdominal vasculature to superficial blood vessels in order to prevent a fall in blood pressure (Cronje, 2007), and to ensure that the body’s heat can be dissipated more rapidly. As blood is shunted from the central circulation to the muscles and skin to facilitate heat dissipation, perfusion of the visceral organs is reduced, particularly in the intestines and kidneys.

In their study on humans Bouchama & Knochel, (2002), described the physiology of what is called ‘heat-stroke’ as being the condition that occurs when the core body temperature in humans suffering from heat-stress, rises above 40^{o} C for prolonged periods. When the intestinal blood supply is severely restricted for such prolonged periods, toxins from the intestinal bacteria can cause enterotoxaemia, resulting in organ failure, with the result that heat-stroke can lead to death (Armstrong *et al.*, 2012; Gaffin *et al.*, 1998).

In mammals an elevated blood temperature causes tachycardia, increases cardiac output, and increases minute ventilation (panting) (Gaffin *et al.*, 1998; Van de Pere *et al.*, 2010). Van de Pere *et al.* (2010) showed that pigs panting during unloading had a lower pH after slaughter and commented that the percentage of panting pigs can give information about their meat quality.

Xiong *et al.* (2015) reported that pigs became heat-stressed at ambient temperatures greater than 27^{o} C and less than 5^{o} C. Haley *et al.* (2008b) found that at temperatures in excess of 30^{o} C, with relative humidity in excess of 88%, both sensible and evaporative cooling mechanisms for the pigs were severely compromised. Recommendations by the CANADIAN AGRI-FOOD RESEARCH COUNCIL (2001), to ensure that 100kg pigs remain in their thermal comfort zone, are that during transport temperatures should be kept between 10 and 21^{o} C.

Heat-stroke can be either *exertional* (as a result of strenuous exercise) or *non-exertional* (as a result of exposure to high environmental temperatures). Heat-stroke results in hypotension, inadequate organ perfusion, and coagulopathies, all of which are secondary to increased intestinal permeability. The extent of damage to the intestinal wall and the magnitude of endotoxin leakage into the circulation are critical determinants of multi-organ failure and mortality (Armstrong *et al.*, 2012). Administration of anti-endotoxin antibodies before heat-stress occurs, attenuates haemodynamic instability and improves outcomes, suggesting that endotoxin is involved in the progression from heat-stress to heat-stroke (Bouchama & Knochel, 2002).

The most serious complications of heat-stroke fall within the category of multi-organ-dysfunction syndrome. They include encephalopathy, rhabdomyolysis, acute renal failure, acute respiratory distress syndrome, myocardial injury, hepatocellular injury, intestinal ischaemia or infarction, pancreatic injury, and haemorrhagic complications, especially disseminated intravascular coagulation, with pronounced thrombocytopaenia. These features suggest that the tissues of animals surviving heat-stroke will be compromised, and thus could impact on subsequent meat quality.

Differences between the animals used in different transport studies

<u>*The impact of genetics on transport stress*</u>: Stress-susceptibility in the pig has been mapped to a single recessive gene, the ryanodine receptor 1 gene (RYR1), commonly called the halothane gene (HAL), (Basic *et al.*, 1997; Green *et al.*, 1997; De Smet *et al.*, 1996; Fujii *et al.*, 1991). Similar genes have been found in humans, cats, dogs, horses and giraffes (Basic *et al.*, 1997).

The defective ryanodine receptor affects closure of calcium channels in the sarcoplasmic reticulum in muscles that causes a sudden, sustained rise in intracellular calcium with consequent muscular contraction and upregulation of muscle metabolism. It has been suggested that the leakage of calcium causes involuntary exercising, resulting in improved muscling and reduced fat in pigs (Kathirvel & Archibald, 2001) which led to the involuntary selection of pigs that carried the defective receptor by pig breeding companies.

Few transport research articles report the presence or absence of the HAL gene in the pigs that were studied. However, it is apparent that many Northern Hemisphere pig breeding companies knowingly include the heterozygous genotype to capitalise on the commercial benefits that result from its inclusion (Green *et al.*, 1997). In New Zealand both of the two major pig breeding companies have ensured that none of their breed lines have the HAL gene, either in the homozygous or heterozygous forms (pers. com.).

Porcine Stress Syndrome (PSS) is a term used for the effect of the genetic defect in pigs that has emerged through genetic selection for fast, lean growth. There are considered to be three manifestations of PSS – (i) sudden death, (ii) the production of pale, soft, exudative (PSE) meat, and (iii) malignant hyperthermia (MH) (Kathirvel & Archibald, 2001; Basic *et al.*, 1997).

(i) Pigs may be found dead after times of stress such as handling, sexual intercourse, parturition, excessive ambient temperatures or (most commonly) during transport.

(ii) The quality of a pig's meat can be impaired by it becoming pale in colour, lacking firmness and having a reduced water-holding capacity.

(iii) Affected pigs will have been hyperthermic, panting excessively, have a rapid heartbeat, have muscle tremors and the skin becomes blotchy, erythematous and cyanotic. These symptoms are most often associated with the use of halothane anaesthesia.

Porcine Stress Syndrome leads to an increase in metabolism and intense production of heat, carbon dioxide and lactic acid, with contraction of skeletal musculature that can affect the meat quality of surviving animals.

Homozygous pigs are sensitive to halothane and are susceptible to PSS. De Smet *et al.*, (1996), when looking at meat quality traits, showed that heterozygous pigs were intermediate between pigs that lacked the gene and homozygous pigs. Pigs that are heterozygous are generally resistant to PSS but have intermediate levels of fat when compared with homozygous or resistant animals (Kathirvel & Archibald, 2001). Since affected pigs often had more developed musculature and larger carcass weights, the genes translating PSS were often favoured when selecting breeding stock. Controlled exposure of pigs to halothane gas can be used to identify homozygous animals and these can be removed from breeding programmes. However, despite the availability of a DNA test that can detect heterozygous animals, it is unlikely that such animals will be completely eliminated from breed lines because they can have superior carcasses and better feed conversion efficiency (Basic *et al.*, 1997; Green *et al*., 1997).

Fujii *et al.* (1991), found that five genetically distinct breeds carried the same mutation in the RYR1 gene suggesting that either the mutation had been introduced from a single common source or that the mutation had recurred and been selected for in each of the breeds separately. Weschenfelder *et al.* (2013), showed that despite the recognition of the impact that such genes have on meat quality and mortalities, some modern breeds such as the Pietran show a higher responsiveness to handling stress than other breeds. Adzitey, (2011) also noted that high lean pigs such as the Pietrain and Hampshire appeared more susceptible to stress than pigs with less muscle development.

There is little genetic variation amongst commercial pigs in New Zealand. The two major pig-breeding companies have ensured that the stress-related halothane gene that leads to malignant hyperthermia is not present in their breed lines. However, both of the New Zealand breeding companies have sourced genetic material, including semen from Pietrain breed lines, from North American and various European countries. Despite that, the breeding programmes used by the New Zealand breeding companies mean that pigs from their breed-lines will be different from pigs born in North America or Europe. As a result, the genetic susceptibility to heat-stress, in pigs used in international studies, will be different to the susceptibility of New Zealand pigs, making the results of international heat-stress studies difficult to interpret.

<u>*Psychological responses of individual animals*</u>: Some humans (and other animals) seem to be more vulnerable to stress-related disorders than others (Gaffin *et al*., 1998; Hubbard *et al*., 1977). Sapolsky (1990), as a result of his work with baboons, suggested that human psychological and social characteristics (for example, their emotional makeup, personality and position in society) can influence their physiological response to stress. He was able to show that a baboon's position in a group's hierarchy influenced the level of stress that the individual experienced. Pigs are also an hierarchical species and

could therefore be expected to have individuals that were affected by environmental stressors to a greater or lesser extent, than other individuals, as noted by Grandin, (1997).

The stress response of an animal can be triggered by an actual insult (a physical stressor), such as heat or the attack of a predator, or by the mere expectation (a psychological stressor) that an insult is about to be delivered (Sapolsky, 1990; Grandin, 1998). Pigs are an intelligent species with a wide range of vocal alarm calls. When presented to a person with whom they are not familiar, their immediate response is to vocalise and run away (Grandin, 1997; White, 1995). Both of these responses lead to the rest of the group following suit. If the group perceives that the stranger does not pose a threat, they will approach them and investigate their presence. Such behaviour suggests that, like the baboons, pigs are likely to be subject to psychological stressors with individual animals being more susceptible to stress than the rest of the group.

The effect of a pig's health on transport stresses: Subclinical disease is an illness that stays below the surface of clinical detection; there are no signs or symptoms that can be recognised (Medterms medical dictionary). Despite any observations made by either the farmer or the truck driver, some pigs may have a compromised health status when being loaded. Such conditions as moderate lung pathology (Carr *et al.*, 2005; Intraraska *et al.*, 1984), or compromised cardiac function (Zurbrigg *et al.*, 2017), leave the pig with few outward signs.

Porcine Respiratory and Reproductive Disease (PRRS), a significant and often fatal cause of pneumonia, is widespread in all Northern Hemisphere countries (with the exception of Sweden) but is not present in either Australia or New Zealand. However, *Mycoplasma hyopneumoniae* (*M. hyo.)* another cause of compromised lung function in pigs, (Carr *et al.*, 2005; Intraraska *et al.*, 1984), is present in all pig-producing countries worldwide including New Zealand (Macpherson & Hodges, 1985). Carr *et al.*, and Intraraska *et al.*, both stated that pigs with reduced lung capacity may be more likely to experience acute acidosis and exacerbate the 'downer pig' syndrome.

Pigs with reduced lung capacity due to *M. hyo.* pneumonia may experience hyperventilation to maintain blood pH near homeostasis (Intraraksa *et al.*, 1984). Intraraksa *et al.*, stated that this condition may lead to acute acidosis under stress conditions, however, their study was undertaken on young pigs that were well before market weights. It is possible that much of the lung pathology had resolved by the time that their pigs had reached market weights so that the impact of the lung disease on stress at slaughter might have been minimal. Observation of the lungs of pigs at slaughter throughout New Zealand, has shown that many pigs have *M. hyo.* lesions (personal observation); further work on this observation would be valuable for New Zealand pig farmers.

Both lung diseases and *Actinobacillus pleuropneumoniae* ('pleuro.'), another common lung pathogen found in pigs in New Zealand, can be found in subclinical carrier animals that cannot be recognised by researchers, farmers or truck drivers. Such carrier animals could be more susceptible to excessive heat or compromised ventilation systems and their presence could impact on the results of transport stress studies. The present study looked at pigs from two farms, both of which had a low level of *M. hyo.* making their health status very comparable but possibly different from those pigs that were used in international research studies.

The impact of gender on the results of transport studies: Surgical castration of pigs (henceforth called 'barrows') is commonly performed in many countries overseas but is not permitted in New Zealand. Chemical and surgical castration have been shown to alter a pig's behaviour, providing less aggression, faster growth rates, increased body fat deposition and improved meat quality.

Mota-Rojas *et al*. (2012), Cobanovic *et al*. (2016), Becerril-Herrera *et al*. (2007) and Guardia *et al*. (2005) showed that there were significant differences in the responses to stress during transport, between genders. Becerril-Herrera *et al*., showed that more females stood during transport and more males arrived lying down, an effect that affected carcass yield, whilst Sionek & Przybylski (2016) quoted a report from Guardia *et al*. (2005) that showed a 7% higher incidence of Dark, Firm, Dry (DFD) meat quality defects in females and castrated pigs than in males. Peterson *et al*. (2017) noted that high subcutaneous fat levels inhibits heat transference to the environment, suggesting that the way in which barrows respond to heat-stress may be different to other genders.

Few of the international studies that have been cited, looked at single-sex loads of pigs. As a result, every study will have had a different ratio of females, to males or barrows, leading to a potential difference in the stress levels that occurred during the studies. In New Zealand all farms supply mixed gender pigs for processing, as a result from week-to-week the balance of males to females will vary leading to the possibility that stress levels could vary from one load to the next and could be different to results from international studies.

<u>*The impact of hormonal and growth-promoting agents on the results of transport studies*</u>: Few researchers have included the use or absence of chemical metabolic alterants in their methodology leaving a question as to whether their results can be compared with those using untreated pigs. Internationally, the two most commonly used chemical agents are Improvac® (Zoetis) and Paylean® (Elanco). Porcine somatotropin (PST), is an anabolic steroid (Harrell *et al*., 1997; Etherton, 1988) that is used in North America, but few other countries including New Zealand, permit its use.

The use of such chemical agents as ractopamine-HCl (Paylean®) and vaccination with the synthetic gonadotrophin-releasing factor (Improvac®) are used in the Northern Hemisphere (Zurbrigg *et al*., 2017; Athayde *et al*., 2013; Fitzgerald *et al*., 2009; Marchant-Forde & Marchant-Forde, 2009; Ellis & Ritter, 2005; Grandin, 2002) and Australia. Ractopamine is not used in New Zealand but some pig farmers are able to use Improvac® to reduce 'boar taint' in their male pigs; Improvac® is also used in many of the male pigs in Australia and Britain for 'chemical castration'.

Ractopamine is used to improve feed efficiency, increase carcass weights and reduce the production of fat in pigs and cattle. It has been banned in Europe, Russia and China. Of importance to transport stress, Elanco (McMullen, 2007) advises that the use of Paylean® may increase a pig's susceptibility to stress. Hence, the use of chemical growth-promoting substances could have a significant impact on the physiology and behaviour of pigs, but their use is rarely recorded in the studies cited.

Improvac® is a vaccine, developed in Australia, which blocks the production of testosterone and androstenone in pigs, this producing a similar effect to surgical castration. Countries such as Australia and New Zealand, where surgical castration is not used, use Improvac® to reduce excessive male behaviours such as fighting and to reduce the masculine meat flavour called 'boar taint'. Whilst available for use in New Zealand, Improvac® was not used on either of the farms in the current study.

Differences in farm and transport management practices between studies

<u>*The impact of fasting on transport and lairage stress*</u>: Cronje, (2007) stated that the consumption of diets containing high levels of finely ground grain (as is common practice for pigs in New Zealand) gives a greatly increased susceptibility to heat-stress whilst Schrama *et al.* (1996) stated that heat production by

animals decreases with the time since the last feed, therefore the thermo-neutral zone will depend on the degree of fasting.

Guardia *et al.* (2004) and Tarrant (1989) in his literature review, both indicated that the risk of PSE was minimised after pigs had been fasted for periods of both 12 and 18 hours. Averos, *et al.* (2007 & 2008) showed that not fasting pigs before a journey had a negative effect on the risk of mortality but cautioned that prolonged on-farm feed withdrawal is not desirable because it can lead to aggression, which in turn can lead to carcass damage. Guardia *et al.* (2004) noted that liver glycogen was almost completely depleted after 24 hours of fasting.

The feeding of pigs in large commercial piggeries, worldwide, is an automated process with feeding systems being designed to deliver feed in either wet or dry forms. Wet-feed systems deliver a slurry of feed into a trough at computer-controlled times during the day and, often, the night. The pigs consume the feed rapidly and then rest before the next batch of feed is delivered to them, a process to which the pigs become habituated leading to little aggression between feeds when there was no feed present.

There are a wide range of dry feed systems available with food, in either pellet or meal forms being delivered from large silos. Many of these systems use computer-controlled filling of the feed hoppers within the pens in a piggery so that the pigs are able to be fed *ad libitum*, 24 hours a day. Other systems use small hoppers in each pen that are hand-filled. The capacity of the feed hoppers varies from farm to farm but are generally large enough to ensure that, in the event of an emergency such as a power failure, enough feed will be available to the group to allow staff to recognise the problem and have time to respond before the feed in the hopper runs out. As a result, when, as is normal commercial practice, feeders are switched off the night before the pigs are due to be transported, individual pigs will experience a varying period of fasting and, as the available feed diminishes, pigs become restive and aggressive.

Depending on the type of equipment used and the attitude of the farmer towards feed wasted as a result of left-over feed when the pigs are removed from the pen, or the need to manage the level of aggression amongst the pigs that occurs when there is no feed in the hoppers, the degree of fasting will vary from farm to farm. Hence the degree of transport stress related to fasting will vary from study to study.

Travel sickness has been reported by Marchant-Forde & Marchant-Forde (2009), Warriss (1998a) and Bradshaw *et al.*, (1996b). Bradshaw *et al.*, (1996a & b) suggested that travel sickness in pigs can be related to the timing of fasting before travel and responses were aggravated by 'rough' travelling; individual animals may suffer from travel sickness more than others in their group.

<u>*The effect of loading and unloading on transport stress*</u>: The severity of transport stress depends on aspects of loading and unloading as well as the length of journeys, stocking density, group social hierarchies, genotype and climatic conditions (Vitali *et al*., 2014). Goumon & Faucitano (2017), Kephart *et al.* (2014), Averos *et al.* (2008), and Tarrant, (1989) have all stated that loading stock on to a vehicle is the most stressful period for animals during transportation.

The degree of stress on pigs during loading varies from farm to farm. Many farms operate on an all-in-all-out programme where the entire group of pigs that have cohabited from the time of weaning to the time for marketing, are loaded on a weekly basis. Such cohabiting largely resolves hierarchical conflicts by the time that the pigs are due to be transported (Oczak *et al*., 2012). Other, often smaller farms, select pigs that have reached a marketable weight from different pen-groups on the farm, leading to significant conflict amongst individuals in the assembled transport group as individuals try to establish their hierarchy.

The configuration and structure of the farm's buildings and loading areas are unique to each farm. The width of alleys, the presence of right-angle bends in the alleys which lead to baulking, the vigour with which staff move the pigs and whether the pigs have been moved from a well-lit building to a darkened assembly area or vehicle, can all contribute to pre-loading stresses (Goumon *et al*., 2013; Marchant-Forde & Marchant-Forde, 2009; Benjamin, 2005; Grandin, 2002).

The height, width and angle of inclination of the loading ramp, the presence of sharp projections and the use and spacing of the cleats on the ramp floor can all contribute to loading stresses (Faucitano, 2013; Grandin, 2002; Tarrant, 1989). Once inside the vehicle the layout of the pens, the smell of effluent from other animal species (Lewis *et al*., 2010), the unfamiliar floor materials that introduce both tactile and auditory stresses all cause pigs to hesitate when first entering a vehicle.

Increasing the loading time has been shown to decrease the risk of getting pale, soft, exudative (PSE) meat upon slaughter (Guardia *et al*., 2004); Guardia *et al*., hypothesised that short loading times may be used as an indication of poor handling practices. Anderson *et al*., (2002) showed that bad handling practices can lead to metabolic acidosis making pigs more likely to die during transport or in lairage.

Unloading practices will vary from one study to the next and will create similar stresses to the process of loading. The length of time that the vehicle had to wait before being unloaded, and the time of day, will have varied from study to study, leading to varying stationary periods during which heat, and humidity could have built up within the stock-crates. Most often unloading occurs late in the morning or during the middle of the day when heat from the sun would be at its maximum. In North America a number of packing plants have provided shelters for waiting vehicles that have banks of fans to provide air flows to cool or reduce humidity within the waiting stock-trucks (Lenkaitis *et al*., 2007); none of the international studies cited have reported whether such assistance was available.

The internal configuration of the stock-crate will impact on the ease with which pigs could be off-loaded and thereby the stress that the pigs would have experienced before entering the lairage facilities. Sutherland *et al*. (2009a), supported by the study by Sommavilla *et al*. (2017) have shown that pot-bellied vehicles led to greater unloading stress than flat-deck vehicles and that the internal configuration of stock-crates can influence the amount of transport stress that animals experience. Many stock-trucks in North America unload from the side of the stock-truck rather than the rear, as universally occurs in New Zealand; a feature not mentioned in the literature studies cited. Pot-bellied vehicles are common in North America (including Canada) but are not seen anywhere else in the world.

The impact of stocking densities on transport stress: The number of pigs born on any farm will vary from week to week leading to a variation in the number of pigs available when they are ready for marketing. In North America, many packing houses require farmers to supply the same number of pigs for slaughter every week and impose financial penalties for over or under supply. The payment schedules in North America are designed to encourage farmers to supply pigs of an optimal weight range, financially penalising farmers for the supply of pigs outside of that range. As a result, farmers apply different management strategies to ensure that weekly loads of pigs are of the same number and weights and thereby meet the demands of the packing houses.

In New Zealand abattoirs do not penalise farmers based on weekly numbers supplied. As a result, the pig numbers and pig weights show more variation in New Zealand than in North America (personal observation). Vehicle stocking densities used by drivers in New Zealand are based on a standard number of pigs per pen without reference to the variation in the size, weight or sex of the pigs. It would therefore appear that there could be a significant difference in the impact that stocking densities in New Zealand could have on transport stress when compared with international studies.

Pen sizes within stock-crates are determined by the transport operator who will decide what dimensions will be needed for the type of stock and size of client farms that their business is aimed to accommodate. In New Zealand the main determinant for how many animals can be carried on a stock transporter is the total weight of the loaded vehicle. Guidelines have been set out in national codes of transport and welfare that indicate the number of animals that can be transported, however the codes do not stipulate stock densities but indicate what a driver should do to ensure that the stock being transported are as comfortable as possible (NEW ZEALAND STOCK CRATE CODE FOR THE TRANSPORTATION OF LIVESTOCK, VERSION 4, 2004; STANDARD FOR TRANSPORTING PORK AND BACON WEIGHT PIGS FOR SLAUGHTER, PQIP, June 1995, NZ LIVESTOCK TRANSPORT ASSURANCE MANUAL, June 2013).

Sutherland *et al.* (2009b) state that *'The behaviour of an animal during transit is also an important factor to take into consideration when determining the appropriate space requirements during transport. Adequate space allowance during transit is important because pigs generally prefer to lie down after a period of standing if the conditions are suitable.'*

Stocking densities on vehicles have been shown to have a significant impact on DOA and DIY pigs (Haley *et al.*, 2010; Ritter *et al.*, 2006; Warriss, 1998b). Schrama *et al.* (1996) pointed out that stocking density may restrict postural thermoregulation by determining whether pigs were able to stand or lie down. When stocking densities are too loose animals can be thrown about and may suffer injuries, if too tight, the build-up of body heat through obstruction of airflow can lead to respiratory difficulty and potentially life-threatening heat-stress.

Ritter *et al.* (2006), when looking at floor space during transport, recommended that where floor space allocations were decreased the number of pigs being transported should be decreased. The decision on how many pigs can be penned together lies with the driver. To provide for optimal animal welfare, conscientious drivers reduce pen stock densities in the summer months and increase the densities during the winter months; Grandin (2002) recommends a reduction of between 15 and 20%.

Norton *et al.* (2013) and Kettlewell *et al.* (2001a) noted that the shape, size and number of animals being transported had a significant effect on air flows within crates. In New Zealand, market-weight pigs that are transported are most often either porkers (average weight 50 kg) or baconers/breeders (average weight 90 kg). However, international studies often use market-weight pigs that are heavier than those transported in New Zealand. In their studies Xiong *et al*. (2015) used pigs that ranged from 127 to 136 kg whilst Weschenfelder *et al*. (2013) used pigs that were 115 ± 5 kg, raising the question of the significance of their findings to New Zealand conditions.

As is recommended in the Canadian guidelines for the transport of animals (THE WELFARE OF ANIMALS ORDER 1997), authors such as Haley *et al*. (2010) base their space allowance studies without reference to headroom. The majority of studies that look at space allowance refer to floor areas only, presumably because headroom is fixed in any given transport vehicle, and only the number of pigs per square metre can be modified. However, it would appear that such studies would be more relevant if the space allowance was calculated in terms of cubic capacity rather than floor area. As Haley *et al*. (2010) noted, as space allowance decreases internal trailer temperatures and humidity increase and the pigs' ability to cool themselves, using evaporation from the skin or mucosal surfaces, or lying on the wet floor, is compromised. Because of the reduced vapour pressure gradient when humidity inside the trailer is high, such problems would be exacerbated by restrictions in ceiling height.

In their review article, Brown-Brandl *et al.* (2004) reported that as a pig's body mass increased, heat and moisture production increased. In the studies of the fasted pigs that were examined in their study, the average heat production of a porker (average live-weight 50 kg) was approximately 90 watts/pig, and baconers (average live-weight 90 kg) averaged 130 watts/pig. This suggests that differences in body mass may dictate the optimal space allowances to be used in a crate, to ensure maximum animal welfare.

Fitzgerald *et al*. (2009) noted that of all of the factors that were evaluated, numbers of pigs per load accounted for the largest portion of variation in fatigued subjects and total losses. Ritter *et al*. (2006) showed that total transport mortalities were more than two times higher at low (0.4 m^2/pig) compared to high (0.5 m^2/pig) floor spaces on the truck. The Australian APL project 2010/1021.340 found that at a stocking density of greater than 0.5 m^2/pig, the number of loads with deaths in transit was 2.3% compared to 8.0% when stocking densities were either 0.35 or 0.5 m^2/pig.

The above findings do not recognise the differing space allowances that relate to age or body size but do suggest that a stocking density of close to 0.5 m^2/pig should provide optimal comfort for pigs averaging 90 kg bodyweight during transport. To accommodate the effect of body size several authors have calculated stocking densities against weight/m^2. Riches *et al*. (1996) reported an increase in mortalities when loading pressure exceeded 238 kg of body weight/m^2 for pigs of 100 kg. Ritter *et al*. (2006) reported that the percentage of non-ambulatory pigs upon arrival at a packing plant was reduced from 0.62% to 0.27% when loading pressure was reduced from 330 to 269 kg/m^2 and Kephart *et al*. (2014), found that stress levels increased by 13% when stocking densities increased from 295 to 305 kg/m^2. The CANADIAN AGRI-FOOD RESEARCH COUNCIL (1993) recommended a loading pressure of 254-305 kg of body weight/m^2 (depending on ambient temperature) for pigs weighing from 95-104 kg. These findings based on weight/m^2 support the assumption that the pigs used in the overseas data based on m^2/pig related to the transport of heavier pigs than were used in the current study.

Van de Perre *et al.* (2010) found that a stocking density between 0.39 m^2/100 kg and 0.45 m^2/100 kg was significantly related to a higher carcass pH than higher or lower stocking densities suggesting that meat quality would be optimal within that range.

<u>*The effect of mid-journey stationary periods*</u>: Whilst it is inevitable that drivers will stop their vehicles during long journeys, and park-up for short periods ('comfort stops'), few studies (an exception being Kettlewell *et al.,* 2001a) could be found that looked at the effect that mid-journey stationary periods had on conditions within stock-crates. Kephart *et al*. (2014) in their study of bedding requirements during animal transport, noted that the U.S. DEPARTMENT OF TRANSPORT required all stock-transport drivers to have a 30-minute break every eight hours. No comment was included that indicated what drivers were required to do to ensure the comfort of the animals during those stationary periods.

References to heat-stress in the literature focus on the impact that stationary periods have on changes in temperature and humidity within a pen when a vehicle was stationary during loading and unloading (Averos *et al*., 2007 & 2008; Fisher *et al.*, 2004). Later studies that used wind tunnel modelling (Norton *et al*., 2013; Gilkeson *et al.,* 2009*)* suggested that when the vehicle was moving, external pressure fields provide the 'driving force' for internal air flows, and that ventilation was greatly reduced during stationary periods making ventilation during stationary periods a priority.

A few studies, such as that of Norton *et al.* (2013) have looked at the intra-journey heat-stress associated with the transport of animals on roll-on-roll-off ferries, whilst Fisher *et al.* (2002), looked at the impact of stationary periods that mimicked a vehicle being parked in an open environment such as the parking lot at a ferry terminal, or at an abattoir. Authors, including Fisher *et al*. (2004), have noted that both temperature and humidity rise during mid-journey stationary periods, but no studies have been mounted that could provide guidelines to ensure that heat-stress during mid-journey stationary periods does not compromise a pig's welfare. Because of the frequency of such stops, internationally, it would appear appropriate that more studies should be conducted.

Stock-crate design and its impact on transport stress

Norton *et al.* (2013) noted that there were four major factors directly affecting the internal air flow within a stock-crate: vehicle speed, wind direction, vent area and the degree of blockage due to the animals' presence. From an animal welfare perspective, it is primarily in the area of ventilation design where the impact of results extracted from international studies may differ from conditions in New Zealand.

Once a vehicle starts moving air would be drawn out of the pens by the venturi effect of the air flowing along the walls of the stock-crate. As a vehicle moves forward, the air flow external to the vehicle, separates near the front of the stock-crate and reattaches at the rear. This results in a pressure gradient that forces fresh air to enter the rear wall openings and the top of the upper deck, leading to the air inside the stock-crate to exit from the wall openings near the front (Lenkaitis *et al*., 2007). When the air reaches the back wall of the stock-crate, turbulence is created at the rear of the vehicle before the air moves forward through the crate's pens (Norton *et al.*, 2013; Gilkeson *et al*., 2009). Hence the ventilation of the lower front pens of the truck and trailer units, relies on the air moving over the top of the back wall and through the rear wall openings and flowing down through the decks to the front of the stock-crate when the vehicle is moving. When the vehicle is stationary and loaded with livestock, the build-up of heat and humidity are dissipated by air moving out through the wall openings. Airflows within the stock-crates, when the vehicle is either moving or stationary, can be affected by wind flowing through the wall openings (Lenkaitis *et al*., 2017).

Gilkeson *et al.* (2009) used wind tunnels and computer modelling, to reveal that in free air, ventilation of the upper deck of crates was adequate, but that the air was not similarly refreshed on the lower deck indicating that airflows during stationary periods may be compromised. However, when the vehicle was moving, ventilation improved on both the upper and lower decks as the vehicle's speed increased. In their study they showed that the air flow behind the front wall of the lower deck of the crate was minimal compared to either the sides of the pens or the upper decks. They also found that 80% of the air entering the lower pens in the crate in the model, originated from flow through the upper deck when the vehicle was moving.

<u>*Airflows within a stock-crate*</u>: Haley *et al.* (2008b) state '*Although external temperatures and relative humidity are associated with in-transit losses, it is likely that the microclimate within the trailer is equally or more strongly associated with these losses.*'

When animals are loaded onto the lower deck of a stock truck in New Zealand, the floor of the pen above is lowered into place to act as a ceiling. With the exception of the floor on the bottom deck, the floors are designed to prevent animals being exposed to the urine and manure produced by the animals in the deck above them. The floor on the bottom deck is designed to allow effluent from the animals to drain into an effluent tank below the deck. This means that when in place, the upper floors are essentially water-tight and any air flow from the upper decks to the lower decks would be restricted.

An important difference in New Zealand stock-crate design is that the ceiling height in pens are lower than those commonly found in the Northern Hemisphere. The standard New Zealand pen, in a four-deck stock-crate, has a ceiling height of between 750-800 mm where, in the literature cited, ceiling heights were reported as being between 900 and 1100 mm (Xiong *et al.*, 2015; Weschenfelder *et al.*, 2013; Brown *et al.*, 2011; Kettlewell *et al.*, 2001b). Having such low ceilings could be expected to have a significant impact on the air flows in the lower decks when the pens contained pigs.

Using the formula: Height (cm) = 38.8639 + 0.4272 Weight (kg) – 0.0008375 Weight $(kg)^2$, Visser (2014) calculated that the height of a 100 kg pig could be expected to be 730 mm, and a 110 kg pig would require greater than 760 mm of headroom. This indicates that many of the bacon-weight pigs (90 ± 5 kg) that are currently being transported in New Zealand would have only 30 mm of headroom when being transported in a four-deck stock-crate. If, as has been recently proposed by a New Zealand pig-processing company, farmers will be encouraged to grow their pigs to 110 kg, as is common in Australia and the Northern Hemisphere, the low ceilings in four-deck stock-crates could create a significant animal welfare problem.

Another factor affecting air movement within the pens in a stock-crate, is the speed of the vehicle. Universally, the speed of vehicles in residential areas is restricted whilst the speed on open-roads varies from country to country. The speed of the vehicle will also be affected by the topography of the region through which the vehicles travel. Therefore, depending on the relationship of the packing plant or abattoir to the farm, air movement within pens will vary from study to study.

The thermal micro-environment around animals during transport: The environment in the pens within a stock-crate is a combination of external factors (sun, wind, rain and heat from the truck's motor) plus the heat and humidity produced by the pigs and any humidity or gases arising from evaporation of liquid held in the effluent tank or condensation on the crate walls. Movement of the pigs, combined with any air flow created by wind entering the pen through the wall openings, plus the efflux of air through the wall openings caused by the temperature differential between the inside and outside of the stock-crate, would create a variable environment within the pens.

The heat exchange between pigs and warmer or hot environments is influenced by several factors in addition to air temperature. Hoff (2006) noted that pigs lose or gain heat through conduction, convection radiation and evaporation. Factors such as solar and thermal radiations (such as from the vehicle's engine), air speed, atmospheric water vapour pressure and the temperature and wetness of the floor, all impact on heat exchange. High levels of humidity can lower the temperature at which animals will begin to experience heat-stress because it limits evaporative heat loss, effectively amplifying the effects of high temperatures.

Various means of alleviating heat-stress include providing shade, increasing air speed (for example, by the use of fans), sprinkling water over the pigs (to increase evaporative cooling from the body surface) or reducing vapour pressure (by using fans to force humid air out through the wall openings). However, so long as dry-bulb air temperature is kept below 30^{o} C, even very high humidity does not compromise a pig's ability to lose metabolic heat at a rate necessary to ensure heat balance and homeothermy (Curtis, 1983).

An increase in air movement within pens, disrupts the thermal insulation provided by the boundary layer of air around an animal, causing an increase in convective heat loss. The extent to which air movement causes an increase in heat loss is dependent on an animal's body weight, the temperature of exposure and whether it is kept individually or in a group (Schrama *et al*., 1996). Low air velocity changes are proportionately more effective in increasing heat loss than similar changes at high wind speed and values for groups of animals are less than those for individuals (Close, 2020).

The bottom front pen, where the majority of pigs that were DOA (as noted in the pre-study report), appears protected from many external environmental influences. It is sheltered behind the cab of the truck and its ceiling is not subject to the influence of the sun when animals are being transported on the second deck. The floor, as well, appears insulated from ambient conditions by the truck's deck and a 100 mm deep effluent tank that is emptied of fluid contents, leaving a layer of moisture of varying depth at the beginning of each journey.

Air within the front pens would be augmented by air from the rear pens (Norton *et al.*, 2013). The limited amount of additional air entering the bottom front pen from the rear of the stock-crate would be influenced by heat and moisture from the pigs in the rearmost pens with further restriction of air flowing towards the bottom front pen being created by the wall-partitions separating the pens on each deck.

The effect of pen location on transport stress in pigs: The abattoir pre-study report showed that 86% of the DOA pigs had been found on the bottom deck of the truck or trailer, with more being found in the bottom front pen than in any of the other pens. Pens on the upper decks and the middle pens of the truck and trailer had the lowest percentage of DOA pigs. Sommavilla *et al.* (2017), Newman *et al.* (2014), Kephart *et al.* (2010), Ellis *et al*. (2008) and Brown *et al.* (2007) all found that the bottom front pen in a stock-crate was particularly vulnerable to the effects of heat-stress. In New Zealand and in many of the international studies, the pigs in the bottom front pen would have been the first to have been loaded at the farm and would have been the last to have been unloaded, thereby having spent the most time on board the stock-truck.

Brown *et al*. (2007) and Ellis *et al*. (2008) both found that the average temperatures recorded in the front pens of a stock-crate were warmer than the pens at the back of the crate, with Brown *et al*. (2007) measuring the difference being approximately 2° C higher than the average. Gilkeson *et al*. (2009) and Norton *et al*. (2013), using computational fluid dynamics, calculated that the poorest region in terms of air exchange rate would be found at the front pens of a stock-crate.

Much of the North American work that has looked at the impact of the bottom front pen, has been conducted using pot-bellied transporters where the position of the bottom front pen differs from the transporters commonly used in New Zealand. Researchers have pointed out that conditions in the bottom front pen of both pot-belly and flat-deck transporters were often unfavourable (Brown *et al.*, 2007 & 2011). Brown *et al.* hypothesised that this effect may largely be due to the aerodynamics of the trailer that leads to reduced ventilation in those compartments; this contention was supported by the findings of Gilkeson *et al.* (2009). Brown *et al.* (2011) also pointed out that those compartments are in close proximity to the vehicle's engine, drive-wheels and transmission, and are directly behind a solid wall that has no ventilation openings, and suggested that heat from the vehicle's engine and transmission may be a factor to be considered.

Ambient air enters the back of the vehicle when it is moving and gradually becomes warmer and more humid as it passes over the pigs in the rear pens (Brown *et al.*, 2011). Consequently, this air will have less cooling value when it reaches animals in the front pens. Additionally, pens in the lower decks will have heat added to them from the animals being transported in the deck above them.

Whilst a number of authors have commented that pens in the front of a stock-crate are more stressful than pens at the rear of the crate, a wide range of variables such as the type of vehicle used, the size and weight of the pigs being surveyed, the weather and season, distances travelled, whether the pigs had been fasted or had been given chemical agents that are not available in New Zealand, all make the relevance of the international findings difficult to correlate with New Zealand conditions.

Differences in the heat measured in different pens within a stock-crate: Heat on the upper deck of a stock truck is affected by solar radiation and air flows that are different to those of the lower pens. Depending on ambient conditions, animals on the upper deck may experience greater or lesser heat than animals in the lower decks (Weschenfelder *et al.*, 2013). Ellis *et al*., (2008) found that temperatures in the compartments on the upper deck tended to be slightly higher than the compartment directly below. They suggested that this may be due to a combination of heat rising from the bottom pens to the top deck and also to the incident solar radiation coming through the roof of the trailer.

Lewis *et al.* (2010) found that the temperature remained stable (almost equal to the outside temperature) during transport (when the vehicle was moving) and that the air temperature in the truck rose during loading and declined as the truck moved. They also found that the air temperature within the stock-crate rose by ~0.8° C per minute when the vehicle was idle and pigs were on-board, indicating that stationary periods were of particular importance to the incidence of heat-stress.

The shape, size and configuration of the wall openings: The 'NEW ZEALAND STOCK CRATE CODE FOR THE TRANSPORTATION OF LIVESTOCK (VERSION 4, 2004)' indicates that the size, shape and positioning of ventilation openings is at the discretion of the transport operators who are legally required to ensure that they are small enough to avoid any animal body-parts protruding from the crates and small enough to minimise effluent escaping from the vehicle. In New Zealand few stock-trucks, or their trailers, have ventilation openings in the back walls of their crates because of the need to avoid dust entering the crates when the vehicle travels down un-paved roads.

Schwartzkopf-Genswein *et al.* (2012), in their review, noted that differences in internal temperatures in pens could be related to differences in wall perforation patterns. Randall & Patel (1994) used a mathematical modelling approach to confirm the 1985 recommendation from the MINISTRY OF AGRICULTURE, FISHERIES AND FOOD TO TRADERS, VEHICLE CONSTRUCTORS AND HAULIERS (UK), that ventilation openings should be a minimum of 20% of the floor area along the total length of the vehicle. Considering the wide variation in wall ventilation patterns in New Zealand, this suggests that further study of the impact that such openings have on pen temperatures could be important for animal welfare.

In New Zealand fibreglass walls are more popular than aluminium walls (Nigel Gordon, Manager, Nationwide Stock-crates, Tauranga, pers. com., 2015) because of their lighter weight when compared with aluminium, and their greater insulation value. However, because of the tendency for fibreglass to tear under the stresses imposed by vibration and the flexing of the walls, care needed to be taken in the design of the ventilation openings. Ventilation openings in fibreglass walls tend to be restricted in number and are either circular or, when elongated openings are used, the openings have rounded corners.

Differences between stock-crate designs in New Zealand and internationally.

The climates, topography and the large size of the pig-farming operations overseas combine to make the type of vehicle and the design of the stock-crates commonly used, different to those used in New Zealand. With the exception of the pig industry in Great Britain, and its associated transport industry, the New Zealand pig industry and livestock transport vehicles are different to those in the countries where the majority of stock-transport studies have been undertaken.

Stock-crates are designed, in large part, to provide for the comfort and security of the animals being transported, but there are wide variations in the design features of stock-crates worldwide and within New Zealand, with the features being largely dictated by the transport company ordering their construction.

Unlike many of the stock-trucks used in North America, that have the truck's motor extending out in front of the cab, the majority of the stock-trucks used in New Zealand are of a 'cab-over-engine' (COE) design. In the majority of New Zealand stock-trucks, the front wall of the stock-crate sits directly behind the vehicle's cab which sits over the engine and drive units, whilst in many of the North American vehicles, the stock-crate is articulated with the cab and drive unit, therefore the front wall of the stock-crate is not shielded by the cab to the same extent as is the case with the standard New Zealand stock-truck design.

In New Zealand stock-trucks are most often provided with a trailer that is towed behind the truck, with the trailer-crate having a similar design and capacity to the stock-crate attached to the cab and drive-unit; the articulated trailer is more manoeuvrable on the winding roads that are common in New Zealand. Articulated trailers are less common in North America and Europe presumably because the roads tend to be less winding and the countryside, where pig-production occurs, tends to be relatively flat making the use of longer, non-articulated vehicles more practical and cost-effective.

Pot-bellied vehicles are widely used in North America and feature in many of the transport research studies (Fox *et al.*, 2014; McGlone *et al.*, 2014a; Brown *et al.*, 2011; Ellis *et al.*, 2008; Kephart *et al.*, 2010), but such vehicles are not used in Australasia. Pot-bellied vehicles have been shown to be more stressful for pigs than flat-deck vehicles (such as are universal in Australasia), largely because of their use of steep internal ramps (Weschenfelder *et al.*, 2013; Kephart *et al.*, 2010).

Worldwide, stock-crates are compartmentalised into pens to ensure that the weight of the stock being transported can be evenly spread across the vehicle's chassis, and the number of decks within the stock-crate is largely determined by the size of the animals that are to be transported. In all countries vehicle width and height are very similar, but vehicle length and vehicle weight may be restricted and thereby create limits to the number of animals that can be transported per load.

In New Zealand the number of animals that can legally be transported per load is largely determined by the length and total weight of the fully loaded vehicle. In common with international trends, every effort is taken by stock transport operators to minimise the tare or un-laden weight of their vehicles, as a result both the maximum number of animals that can be transported per load and weight-based road user charges can be minimised. As a consequence of this, crate walls are typically built from either aluminium or fibreglass, with all internal fittings being made from aluminium. The only exception to the use of aluminium or fibreglass is the common use of steel mesh for the floor of the lowest deck.

Environmental conditions in the primary pig-producing countries in the Northern Hemisphere differ markedly from those in New Zealand. In continental Northern Hemisphere climates, stock-crates are designed to accommodate the variation between the extreme cold and snow of winter, and the heat of summer. Northern Hemisphere stock transport vehicles have a solid roof over the top deck to prevent rain or snow from entering the vehicle. In New Zealand, by comparison, the climate is more temperate with little snow or extended periods of high humidity or heat (Macara, 2016). As a result, stock-crates in New Zealand have been designed to provide stock protection from the cold of winter and the heat of summer without the need for adjustments to the crate's structure to accommodate changing environmental conditions. New Zealand stock transport vehicles are provided with a flexible, permeable cover attached to the upper wall of the stock-crate that can be put in place when animals are being transported on the top deck when the driver considers such protection was needed.

To accommodate the cold of the continental regions of the Northern Hemisphere, stock-crates are normally fully enclosed during the winter months making the provision of adequate ventilation a problem. However, to accommodate the comfort of the animals being transported in the heat of summer, wall openings are left uncovered to provide maximum ventilation. In the Northern Hemisphere, to improve air-flows, various configurations of fans and systems for misting, or the sprinkling of water, are increasingly being used in transport vehicles during both the winter and summer months (Sommavilla *et al.*, 2017; Xiong *et al.*, 2015; Nannoni *et al.*, 2014; Fox *et al.*, 2014; Averos *et al.*, 2008).

The use of bedding materials in transport vehicles in countries such as Canada, the United States, Europe and Britain, has become obligatory during cold months (HEALTH OF ANIMALS REGULATIONS PART XII, CANADIAN FOOD INSPECTION AGENCY, 2001; EUROPEAN COMMISSION, SCIENTIFIC COMMITTEE ON ANIMAL HEALTH AND ANIMAL WELFARE, 1999). However, frozen condensation-moisture inside stock-crates or within bedding materials during winter can contribute to injuries and mortalities amongst stock being transported in the Northern Hemisphere (McGlone *et al.*, 2014a); such conditions have not been reported in New Zealand. The Northern Hemisphere regulatory organisations also recommend the use of 'boards' to close some, or all of the ventilation openings in the walls of vehicles, and timber panels to line the inside of the crates to keep transported stock warmer and prevent frost-bite during severe weather.

In New Zealand, the emphasis in stock-crate design has been to ensure an adequate amount of wall ventilation through all seasons, and 'boarding' or fan-assisted ventilation and bedding materials are not used.

The effect of journey distances on transport stress

Transport distances of greater than 12 hours are common in Europe (Fiore *et al*., 2009; Warriss 1998b) with pigs frequently being transported from the cooler northern countries to the milder climates of Italy or Spain. Current European legislation defines long journeys as those that exceed 8 hours. In North America, very large numbers of pigs are born in Canada or the Eastern states of the USA and are sent for finishing to farms in the Corn Belt in the United States, resulting in considerable transport distances being experienced.

As Nielsen *et al.* (2010) state '*There are four aspects of animal transport, which have increasing impact on welfare as transport duration increases. These relate to (i) the physiological and clinical state of the animal before transport* and *the physiological and clinical state of the animal during transport (ii) feeding and watering (iii) rest and (iv) thermal environment. It is thus not journey duration per se but these negative aspects that are the cause of compromised welfare.'*

There are variable results from studies that have looked at the impact that journey length had on transport stress. A study by Becerril-Herrera *et al.* (2007), found that the incidence of bruising, redness of the skin, shaky-leg syndrome and the number of pigs lying down after travel, all increased with increasing journey duration. Longer journeys gave a greater opportunity for some stressors such as vehicle vibration to impact on the welfare of animals during transport, but even short transport distances can compromise an animals' welfare if pre-transport factors were not optimal (Werner *et al*., 2007).

Tarrant (1989), stated that because the main stressors occurred during loading and unloading, short transport distances would appear to be more stressful than long distances. Guardia *et al.* (2004) showed that the highest risk of PSE meat occurred in short transits carried out at lower stocking densities. It was proposed that lengthening the transport time allowed pigs to recover from the stresses of loading and gave them the opportunity to adapt to their new environment.

A long journey may involve unusually high ambient temperatures, stressful loading conditions, a series of stationary periods, and/or the addition to the load of animals from different farms. Such factors could add to the stress of the animals that were originally loaded that may not occur during a journey of short duration (Nielsen *et al*., 2010).

Averos *et al.* (2008), showed that increases in serum cortisol concentrations in fattening pigs were greater for short (1 hour) compared with long (13 hours) journeys. They suggested that habituation to stress may occur over time so that animals may de-stress as a journey progresses. Mota-Rojas *et al.* (2012) also suggested that pigs showed an adaptation phase during long distance travel.

Nannoni *et al.* (2014) noted that blood lactate measurements are a quick indicator of physical stress as it only takes four minutes for lactate levels to peak after exertional stress. Brown *et al.* (1999), found a significant increase in plasma lactate and cortisol concentrations after pigs were transported for 16 hours. They also showed that plasma protein and albumin concentrations increased with increasing transport distances, suggesting that the animals were suffering from dehydration. A study by Mota-Rojas, *et al.* (2012), concurred with Brown *et al.* (1999), by showing that pigs can become dehydrated as a result of long transport distances.

In New Zealand transport distances for pigs from farm to slaughter facilities are relatively short, compared with Australia and the Northern Hemisphere. However, market forces have, from time to time in the past, encouraged the transport of pigs from Canterbury to Auckland or other North Island slaughterhouses. These journeys would have taken in excess of twelve hours to complete, would have involved lengthy stationary periods during the Cook Strait ferry crossing, and the pigs would have remained on board throughout without food or water.

In New Zealand, the separation of the two main islands poses significant animal welfare challenges for stock being transported between them. Prolonged stationary periods occur when vehicles, loaded with stock, wait on the wharf before being loaded on to the inter-island ferry (Fisher *et al.*, 2004; Fisher *et al.*, 2002). Additionally, stock may suffer from ventilation problems on the ferry if the truck or trailer is parked between decks rather than on an open deck (Norton *et al.*, 2013).

Distance travelled may not reflect the actual length of time that stock may be exposed to travel stressors. It is common practice, where animals from two separate farms are to be transported on the same vehicle, for animals from the first farm to be loaded onto the trailer first. The trailer is then left parked-up whilst the truck travels to the second farm to load their stock. The truck then returns and re-attaches to the trailer and completes its journey. Animals on the trailer will have suffered greater stress effects from the increased transport time and stationary period, than those from the second farm.

The effect of driver behaviour on transport stress

Different drivers use different degrees of force during the loading and unloading processes with some using electric goads, loud vocal encouragement and repeated slapping of slower pigs to speed up the loading and unloading processes. Such aversive practices contribute to the stress of animals being transported (Grandin, 2002 & 1998).

Inevitably, stock will be subject to the movement of the vehicle during acceleration, deceleration and the lateral thrusts that occur when the vehicle turns corners. New Zealand's topography is characteristically hilly with winding, often steep roads (angle greater than twelve degrees [Automobile Association, New Zealand]). The main highways are punctuated, at relatively short intervals, by urban developments that require the frequent acceleration and deceleration of the vehicles that pass through them. While gravel roads are not a common feature in the transport of pigs in New Zealand, dust, vehicle vibration and rough road surfaces can all contribute to poor animal welfare when stock are being transported (Dalla Costa *et al.*, 2017; Marchant-Forde & Marchant-Forde, 2009; Peeters *et al.*, 2008; Bradshaw *et al.*, 1996 a & b).

Despite the welfare codes and transport regulations, much of the comfort of the animals falls on the driver's behaviour. Some drivers drive too fast for the road conditions and brake too suddenly for the comfort of the stock they are carrying, making driver behaviour a significant factor in transport stress (Peeters *et al.*, 2008). As a result of these factors, in New Zealand, driver behaviour can be critical to the welfare of the stock being transported. Transport operators in New Zealand often have considerable difficulty in encouraging and retaining drivers to transport stock because of the challenges faced when compared with transporting freight (Murray Writon, Ellesmere Transport Limited, pers. com., 2015).

The effect that ambient conditions can have on different studies

<u>*The effect of climate on transport stress studies*</u>: The climate in New Zealand is influenced by being relatively small islands in the 'roaring 40s' that can experience rapid changes in the weather and rarely have stable weather conditions for extended periods. Overall, the climate could best be described as temperate.

Over the periods between 2016 and 2018 two monthly recordings were taken and averaged to give a picture of the temperature and humidity patterns that occur in Canterbury (Macara, 2016). Those readings indicated that at times Canterbury can experience high ambient temperatures (greater than 35^{o} C) and humidity conditions (80+% relative humidity), and that this typically occurs in the warmer months of the year.

Of 57 overseas field studies that have been cited, twenty-nine were undertaken in Canada and the USA, thirteen in Europe, seven in the United Kingdom, five in Australia and three in Mexico. With the exception of the United Kingdom, those countries experience a continental climate where stable weather patterns can persist for extended periods. Fuquay (1981) noted that the high humidity in the south eastern states of the USA can cause variable production responses in animals thereby indicating that similar variability could also happen during road transport.

Many of these studies were undertaken in regions such as in the USA (North Carolina), Australia (Queensland) and Mexico (Veracruz and Puebla), that can have very high and very low ambient temperatures year-round and high humidity for 24 hours each day for long periods. It was therefore thought that the relevance of those studies, to a study conducted in Canterbury, might be compromised by a disparity in the climatic temperature and humidity conditions.

<u>*The impact of weather and season on transport-related mortalities*</u>: As previously noted, Willis *et al.* (2012) reported that 7.3% of the pig transport deaths in Australia occurred during the summer months compared with 3.5% during the winter months. However, over a three-year period, in the report received from the New Zealand abattoir used in the current study (anonymous), little seasonal variation was noted, with a small bias (a total of 99 pigs versus 93 pigs) towards the hotter months.

Warriss (1998a) reported that high temperatures and relative humidities, such as occur most frequently in the summer months, contribute most to in-transit deaths. It was noted that a stressful microclimate within pens was of greater importance than ambient conditions, making assessments of potential stress based on ambient conditions unreliable. Lenkaitis *et al.* (2007), in their study of the microclimates in transport containers, reported that Lewis & Craig (2006) had found that on average the internal temperature was 1.8^{o} C greater than the ambient temperatures.

Goumon *et al.* (2013) and Scheeren *et al.* (2014) both noted that pigs in the winter in Canada stand more than those in the summer and suggested that the postural difference between seasons may be due to the winter pigs wanting to avoid contact with the cold walls and floors. They noted that frostbite was a significant problem in winter months, a situation not reported in New Zealand. McGlone *et al.* (2014b) noted that wet bedding in winter months could increase the incidence of shivering and suggested that the high DOA rates associated with road transport in Canada, could be due to pigs becoming fatigued as a result of the cold conditions.

Werner *et al.* (2007) stated that between 1999 and 2003, 0.177% pigs died during the three summer months in their German study group compared with 0.132% in winter, a finding supported by other European researchers (Vecerek *et al.*, 2006; Lucas *et al.*, 2000). During the German study, it was noted that in 1999 whilst 0.15% of pigs did not survive transport, lairage deaths were 0.017% of the total number of pigs transported indicating that conditions leading to death on the transport vehicles, were more severe than those experienced in New Zealand.

Haley *et al.* (2010) noted that in Canada transporters are asked to follow guidelines for space allowance on trailers in hot summer weather. When ambient temperatures are greater than 24° C, it is recommended that transporters with 3-tier, 15 m trailers, limit the number of pigs to 203 pigs per load; it is worth noting that pens in such vehicles would have more head-room than trailers typically used in New Zealand. It was expected by Haley *et al.*, that the use of fans might allow a stock transporter to have higher stocking densities and thereby improve the economics of stock transport.

The use of mechanical ventilation systems to improve internal air flows

The objectives for animal welfare legislation in recent years stems from the need to maintain a stable, acceptable thermal micro-environment around animals throughout the whole of the transport period (Kettlewell *et al.,* 2001a). As a means to achieve this several studies have been undertaken to look at a variety of ways, including the use of fans, by which the environment within a stock-crate could be modified.

The effect of passive ventilation systems: In still air, passive ventilation relies on the temperature difference between the inside and outside of the vehicle (Norton *et al.*, 2013). Lenkaitis *et al.* (2007) found that where passive ventilation was used, ventilation rates were difficult to predict and McGlone *et al.* (2014a) found that variable ventilation rates led to different microclimates developing in different pens in a vehicle transporting stock.

Mechanically assisted ventilation systems: Primarily driven by EU legislative requirements, the use of mechanically assisted ventilation systems for stock transport has been reported since the early 1980s. These systems were expected to limit the extreme values of temperature and humidity. Tarrant (1989), quoting Nielsen (1982), reported that studies in Denmark had shown that effective mechanical ventilation in pig trucks had reduced DOA by 50% and DIY by 33%.

Kettlewell *et al*. (2001a) stated '*Appropriate ventilation will have two effects, firstly it will provide a better temperature gradient between the animal and its immediate surroundings for heat exchange, and secondly by removing moisture from the immediate environment around them, it will create an improved water vapour density gradient favouring enhanced evaporative loss.*' Kettlewell *et al.* (2001b) found that in a passively ventilated vehicle, when a vehicle was stationary, internal airflows were primarily driven by the prevailing wind hence the primary value of fan-assisted ventilation would appear to be the moving of moisture from the immediate environment around the animals, and reducing temperature, during stationary periods.

Kettlewell *et al*. (2001a) noted that early attempts to modify the environment within a stock-crate by drilling holes in the headboard, that allowed air to enter the container, failed because such air travelled out through the side grilles in the front pens and would not travel throughout the length of the vehicle. They further stated that '*Using fans to provide air movement within the container can ensure that adequate ventilation is provided for all of the animals throughout the whole transit period (including stationary periods).*'

They also noted that some livestock transport containers already had fans fitted but most, if not all, suffered from some fundamental limitations such as:

(i) The vehicles that had been used had not been designed for the optimal use of the fans.

(ii) Banks of fans had been used and the heat generated by them added to the heat in the pens.

(iii) All of the fans operated at the same time with ventilation being unrelated to pen temperatures.

(iv) No provision had been made for where air entered or left the vehicle.

In their paper they described the use of a prototype mechanical ventilation system, designed by the Silsoe Research Institute in the United Kingdom, using extraction fans situated in the wall of the front-bottom pen. Air ingress was provided for by closing off intermediate wall openings and leaving the two rearmost wall openings (one on each side of the crate) open. The system provided air movement over all of the animals throughout the whole of the transport period and was therefore independent of the vehicle's movement. However, cool air entering from the back of the vehicle would have gradually become warmed and more humid by passing over pigs in the rear pens, such that it had less cooling value when it reached the pigs in the front pens (Warriss *et al.*, 2006). It should be noted that the prototype system relied on closing off wall openings along the sides of the stock-crate.

Kettlewell *et al.* (2001a) found that despite the use of the fans it was noted that during a mid-journey stationary period, the temperature increased to levels equivalent to the temperatures recorded after the pigs had been loaded. When the vehicle started moving again, the temperature dropped, but then stabilised at a temperature greater than the temperature recorded at the beginning of the stationary period.

Warriss *et al.* (2006), using a vehicle of the design used in the Kettlewell *et al.* (2001a) study, found that the temperatures (measured by an infrared thermometer in the blood as it left the sticking wound) of pigs transported with fan-assisted ventilation, were no lower than those of pigs kept in pens with passive ventilation. They concluded that under ambient conditions which were not thermally demanding for the animals, the fan system that they had used was slightly less effective than natural passive ventilation.

The use of temperature/humidity indices

Heat-stress during transport is the result of complex interactions in the physical and biological environments in which the animals are being transported. d'Ambrosio Alfano *et al.* (2011), in their presentation in 'Industrial Health', stated that a reliable assessment of the thermal environment should take into account the whole of the six parameters affecting the thermal sensation (air temperature, air velocity, humidity, mean radiant temperature, metabolic rate and the thermo-physical properties of clothing). They further stated that the need for a quick evaluation, based on few measurements and calculations, has led to the development of temperature/humidity indices (THI).

The use of temperature/humidity indices as a measure of stress has become widespread internationally (d'Ambrosio Alfano *et al.*, 2011; Fitzgerald *et al*., 2009; Hahn *et al.*, 2009; Epstein & Moran, 2006; Lee, 1980). Hahn *et al.* (2009) stated that '… *thermal indices have value as secondary measures, serving as* *surrogates for the complex interactions between the physical and biological components*.' According to Lee (1980) the number of proposed indices is legion.

Many limitations are inherent in proposed indices (Dikmen & Hansen, 2009). They include the lack of the quantitative expression of bodily reactions to heat, the need to include important variables that enter into the heat balance, the need to be applicable to a wide variety of circumstances, the need to predict situations that might be encountered in projected operations and the need to be applicable to animals other than man (Dikmen & Hansen, 2009; Lee, 1980). Lee further stated that '*There is no logical way in which even the most easily measured reactions can be integrated into a single overall quantitation of response*.' As a result, an index that is simple is likely to have severe inherent limitations.

Transport operators and their meteorological advisors have developed indices, and charts based on the temperature /humidity indices, that are used to indicate those ambient conditions that could lead to heat-stress in both humans and animals (d'Ambrosio Alfano *et al.*, 2011; Hahn *et al.*, 2009; Epstein & Moran, 2006; Lee, 1980). These charts are often divided into alert/danger/emergency zones (Lucas *et al.*, 2000). However, d'Ambrosio Alfano *et al.* (2011) have cautioned that an index validated in outdoor conditions does not assure its indoor reliability. Moreover, they showed that the outdoor-based index (Humidex Index, which had been adapted from its use in weather forecasting) led to the underestimation of the danger in the workplace and gave a poor reliability for the comfort prediction when it was used in an indoor setting.

Animals during transport are being held in a confined space, more akin to an indoor setting than an outdoor setting. Using an outdoor-based index, such has been used in the current study, raises the question as to whether the use of THI values for the assessment of stress during transport is reliable. Fitzgerald *et al*. (2009), compared seven THI formulae (including the formula used in the current study) when looking at the incidence of DOA and DIY pigs over a twelve-month period that included 12,333 loads of pigs in a North American study. They showed that there were some differences between the results based on the THI formula used, indicating that one needs to understand the limitations of the formula being used when examining THI-based results. An important objective of the current study was to confirm that the THI values recorded reliably equated with the visual appearance of stress amongst the pigs during transport.

The majority of indices use a value-range from zero to 100. Hahn *et al.* (2009) noted that there are differences in the THI values between species because of their physiological differences, particularly in their sensible latent heat dissipation abilities; Fiore *et al*. (2009) indicated that, when using the same formula, pigs had lower THI values than cattle. Supported by the findings of West (1994), Hahn *et al.* (2009) also pointed out, and that in contrast to pigs, cattle THI values less than 70 have little effect on the animals where THI values greater than 75 have been associated with decreased feed intake and milk production.

The formula used in the current study was THI = (1.8 x T + 32) - (0.55 - 0.0055 x RH) x (1.8 x T - 26), [where T = temperature in degrees centigrade and RH = relative humidity in percentage] which was taken from the NATIONAL RESEARCH COUNCIL (1971) (NRC) recommendation that was provided by the NATIONAL OCEANIC & ATMOSPHERIC ASSOCIATION (NOAA). Different authors have used different formulae to produce THI values, but the ranges used indicate that at THI values of 60 to 70 pigs appear comfortable, whilst from 71 to 80, pigs become progressively more stressed. At THI values greater than 80 pigs are severely stressed and are likely to suffer serious metabolic compromise or die. Kephart *et al.* (2014) found that as the THI value at loading rose from 66 to 75, the incidence of DOA/DIY during transport and at the killing plant increased by three pigs per trailer. Nielsen *et al*. (2010), noted that even when pigs did not die their overall welfare was likely to be reduced when overall mortality rates increase.

Design-related requirements in the NEW ZEALAND STANDARD* NZS 5413:1993 *relating to the welfare of animals during road transport

The following sections of the New Zealand standard were extracted to outline the legal requirements for the construction of the stock-crates (truck and trailer) that were used in the current study:

4.1 Stock-crates shall be constructed of metal or other easily cleaned impervious, permanent, non-contaminating material.

4.1.4 Stock-crates shall be constructed with flush fittings so as to avoid protrusions that could cause bruising to stock.

4.4.1 Ventilation gaps shall be as high as is practicable for any given deck.

4.4.3 If over 6 m in length there shall be transverse partitions so no compartment is more than 3 m in length.

4.4.5 All partitions shall be adequately panelled to preclude contamination of stock in one compartment with another and to direct excreta and urine to the deck within the side of the crate.

4.6.2 The design of decks shall be such that stock on lower decks are fully protected from soiling by animal effluent from upper decks.

CONCLUSION

It would appear from examination of the literature, that there are significant differences between the types of vehicles that are used in New Zealand to transport stock, and those that were used in the international studies. Those differences, combined with differences in the climate and the type of animals used in the international studies, indicate that there is a need for road transport studies to be conducted in New Zealand.

Minimum Standard 2e of the TRANSPORT WITHIN NEW ZEALAND, CODE OF WELFARE, 2016, requires that '*Conveyances and containers must be designed to ensure adequate ventilation or oxygenation to allow the free flow of air or oxygen to all animals even when stationary to prevent the build-up of harmful concentrations of gases or impurities, water vapour or temperature.'* Despite this standard, deaths of stock during transport are reported to the Ministry of Primary Industries and animal welfare organisations every year.

Little work has been conducted in New Zealand to examine the conditions that contribute to such deaths. Whilst the death rate amongst pigs in New Zealand appears to be low by international standards, there seems to be little doubt that there will be significant welfare concerns for animals during road-transport.

Internationally, over recent years, considerable research has been directed at ways and means to minimise the stresses associated with road transport. With animal welfare becoming increasingly important to consumers worldwide, the current study was aimed at identifying how the overseas research related to conditions within New Zealand and how the findings could be used to reduce some of the factors that contribute to transport-induced road deaths and compromised animal welfare in New Zealand.

Chapter two

THE VEHICLE DESIGN AND EQUIPMENT USED IN THE STUDY

Introduction

There are a wide range of vehicles used for transporting livestock in New Zealand with very few being similar to the types commonly used in the Northern Hemisphere. Whilst smaller piggeries transport their pigs in a variety of car-trailers or purpose-designed small trucks, the larger piggeries and breeding companies in New Zealand usually employ commercial stock-transport companies to carry their pigs to one of the five plants licensed to slaughter and process pigs in New Zealand.

The numbers of pigs that are required to be transported in New Zealand are small by international standards, so the stock-crates used by the stock-transport companies are universally designed to carry multiple livestock species. However, since the emergence of the porcine circovirus (type 2) in New Zealand in 2003 (Rawdon *et al*., 2005; Garkavenco *et al.*, 2005), pig farmers have become more conscious of the biosecurity requirements associated with pig transport. With the more recent emergence, overseas, of highly infectious viral diseases such as Porcine Epidemic Diarrhea (PED) and African Swine Fever (ASF), the largest of the pig farms in New Zealand have now begun to design their own purpose-built stock-crates and to transport their own pigs as a means of enhancing their biosecurity protection.

In North America, the trucks most commonly used for stock transport have the engines extending out in front of the cab (Figures 1 & 2). Additionally, because of the topography and the large numbers of pigs that need to be carried, and vehicle length not being a critical restraint to stock-truck designs (as it is in New Zealand), 15 to 16 m long trailers attached to articulated vehicles (Sutherland *et al*., 2009a) are commonly used. From the literature cited, and personal observation, it would appear that four-deck stock-crates, designed to carry multiple species are uncommon in the Northern Hemisphere. Because of the size of the livestock industries in North America, Britain and Europe, and the need for tight biosecurity protocols, purpose-built stock-crates designed to carry a single species, are common.

Unlike New Zealand, with its relatively mild temperate climate, in the Northern Hemisphere stock-crates need to be designed to manage the comfort of stock during weather and temperature extremes. As a result, stock-crates need to be fully enclosed during the cold, snow-prone winter months, and have as many ventilation openings as possible, or positive-pressure ventilation systems available, during the hot summer months.

The design of stock transport vehicles in New Zealand has evolved in response to the changing dynamics of the various livestock industries and to the climate and topography of the country. Stock-crates designed for transporting pigs in the Northern Hemisphere commonly have three decks and often have only two decks (Norton *et al*., 2013; Lewis *et al*., 2010; Gilkeson *et al*., 2009; Kettlewell *et al*., 2001a). The number of decks impacts on the height of each pen, leading to the availability of increased airspace above the pigs. Having greater airspace above the pigs may help keep them cooler during summer months, especially if positive-pressure ventilation is employed but, conversely, it may be a disadvantage during very cold conditions.

Pig-specific trailers called 'pot-bellied' trailers (Figure 1) are commonly used in North America and feature in many welfare-related studies. These trailers are not commonly found outside of North America.

Figure 1: A typical 'pot-bellied' pig transporter being loaded in summer in Iowa

Figure 2: A typical North American 'flat-deck' livestock transporter ready for loading in summer

The cladding used in stock-crates needs to be robust and flexible enough to accommodate the stresses of road transport, yet light enough that weight does not compromise the economics of transporting stock. Internationally, aluminium and fibreglass are the most commonly used materials. Aluminium has the advantage of being able to be used for framing as well as cladding, and it can be readily welded or riveted. A potential disadvantage of aluminium is that it is a good conductor of heat, whilst fibreglass has the advantage of providing better insulation than aluminium it tends to tear at points where flexing or movement is high.

When using animal welfare related studies involving road transport, particularly those generated in the Northern Hemisphere, care therefore needs to be taken to recognise that some of the animal welfare findings may not apply to New Zealand. That is, the type of vehicles, the design of the stock-crates, the climate, the topography, and distances travelled that apply in transport-related international studies may all differ markedly from New Zealand.

Description of the truck, trailer and stock-crates used in the study

Truck and trailer design: To minimise as many variables as possible the same truck, trailer and driver were used throughout the study. The truck had a flat deck attached to its chassis and its cab was situated directly over its motor (Figure 3), in what is known as a cab-over-engine style. The truck towed a separate road trailer, which was also of a deck-on-chassis design. This arrangement is almost universal amongst the stock transporters used in New Zealand.

Figure 3: The truck and trailer used for the study unloading at the abattoir

The stock-crates on the truck and trailer were of a type that are common in New Zealand, with an aluminium crate attached to the truck and trailer's decks. The truck and trailer units utilised air suspension which reduced vibration in the stock-crates, an important consideration for managing transport stress according to Dalla Costa *et al*. 2017.

The truck and trailer crates each had four decks designed for the transport of sheep, bobby calves and pigs, but taller animals such as cattle, could be transported by leaving some of the floors still attached to the crate walls by their hinges and latches (Figure 4). Along the length of the truck's crate it was divided, on all levels, into three sets of pens. These divisions were solid-aluminium walls with a 100 mm gap at the top and were fixed to the left-hand side of the crate. Doors, hinged to those fixed walls, could be latched against the right-hand wall creating individual pens (Figure 4). The trailer crate was similarly designed but divided into four pens along its length, with all pens being separated by doors and half-walls.

Figure 4: The inside of the stock-crate

Both the truck and trailer crates had removable flexible covers attached to the top of the walls that could be used for shade or weather protection for stock being transported on the top decks.

The stock-crate was separated from the cab of the truck by a narrow gap (Figure 5) and the truck's engine was situated immediately below and in front of that gap (Figure 6). The truck's catalytic converter (Figure 5) was situated at the front of the stock-crate on the right-hand side above the outlet of the truck's exhaust.

The front and back walls of both the truck and trailer crates were of similar construction with no ventilation openings and, with the exception of the front wall of the truck's stock-crate, had 1.40 m wide slide doors on the right-hand sides. The trailer was towed at a distance, crate-to-crate, of 1.70 m behind the truck.

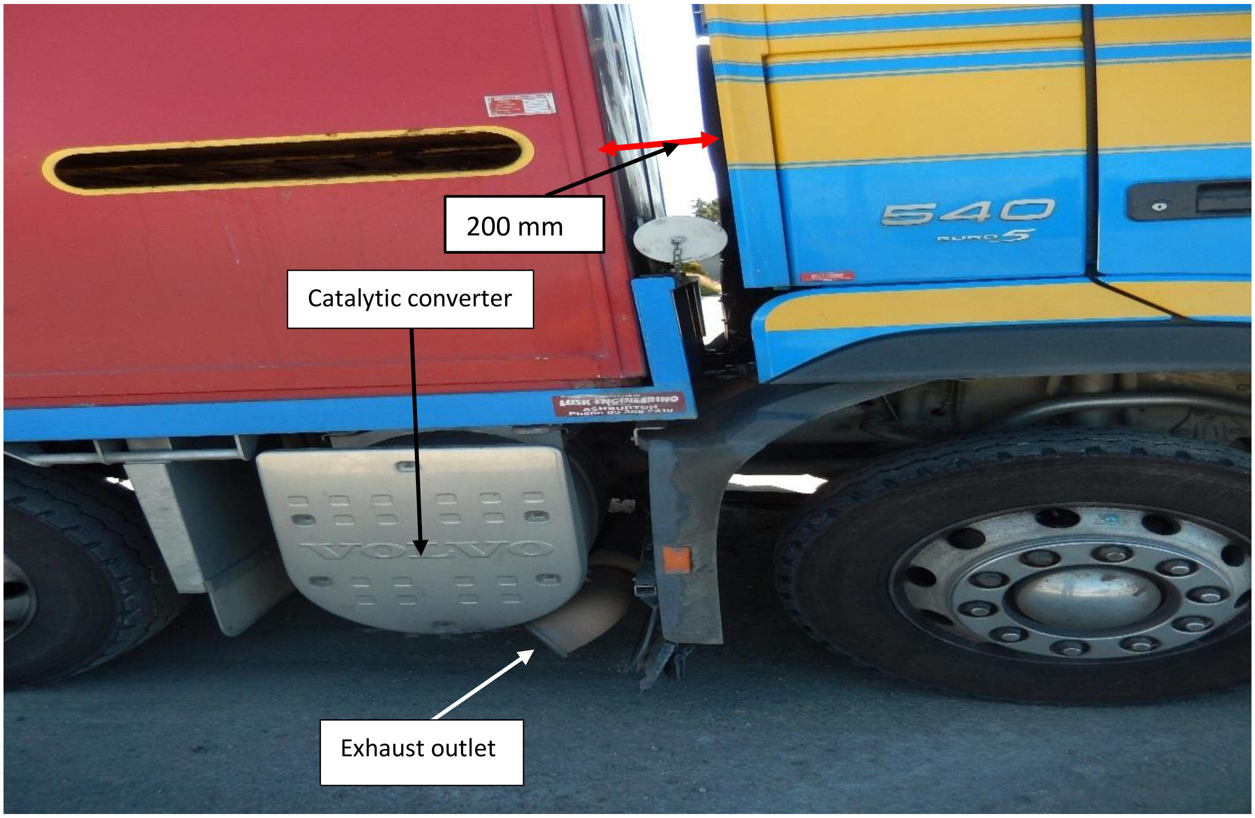


Figure 5: The gap between cab and the crate and position of the catalytic converter

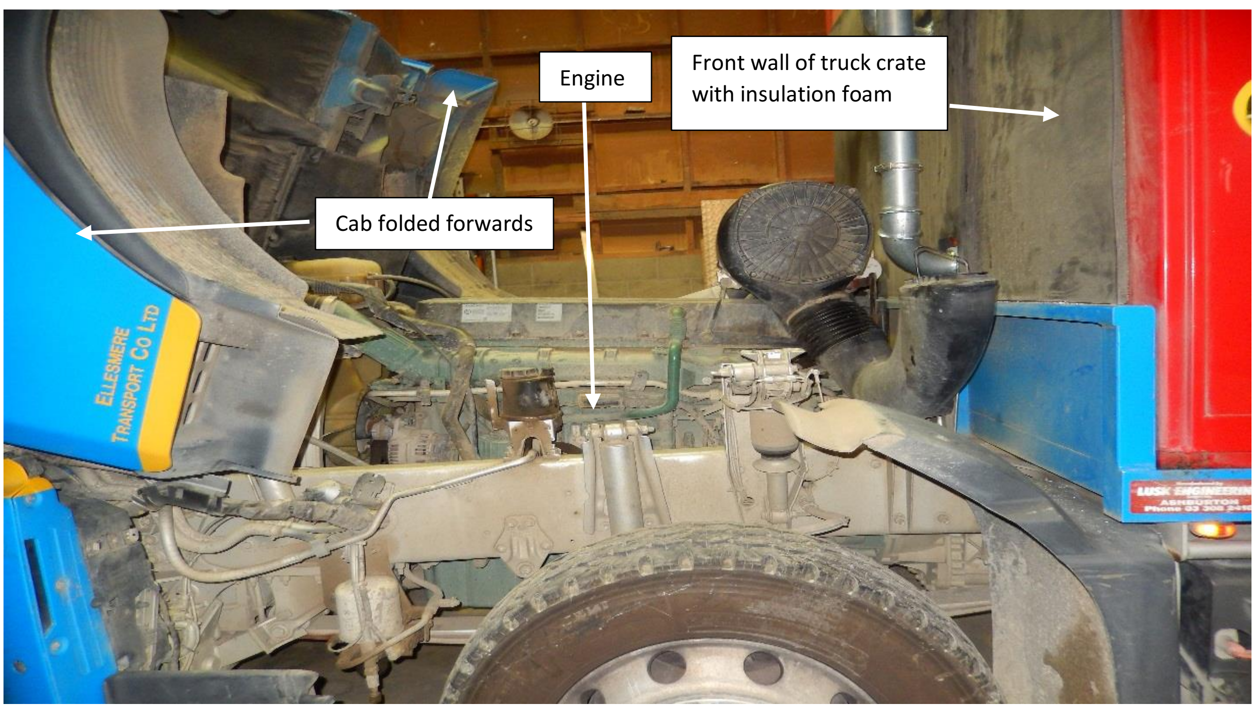


Figure 6: The position of the engine relative to the gap between the cab and the crate

Dimensions of the stock-crates and pens: The truck's stock-crate had the following external dimensions: length 7.2 m and height 3.13 m (giving each side-wall an area of 54.537 m^2); width 2.42 m. The trailer's stock-crate had the following external dimensions: length 8.9 m and height 3.13 m (giving each side-wall an area of 67.414 m^2); width 2.42 m.

The stock-crate on the truck was divided into four decks with three pens per deck, this providing a total of twelve pens in the crate. All of the pens had a width of 2.42 m, and a length of 2.30 m, giving each pen a floor area of 5.566 m^2. The pen heights were 750 mm for the bottom and upper two decks and 800 mm high for the second deck from the bottom, giving each pen a wall area of 3.450 m^2 and 3.680 m^2 respectively.

The stock-crate of the trailer was divided into four decks with four pens per deck, providing a total of 16 pens in the crate. All of the pens had a width of 2.42 m with the front three pens having a length of 2.13 m and the rearmost pens 2.14 m, giving floor areas of 5.155 m^2 for the three front pens and 5.179 m^2 for the rearmost pens.

The pen heights in the trailer were 800 mm for the bottom and third decks and 740 mm for the remaining two. Each of the front three pen walls of the bottom and third deck, had a side-wall area of 3.408 m^2 whilst the top and second deck pen walls, had side-wall areas of 3.152 m^2. The bottom and third deck, front three pen walls, had a side-wall area of 3.424 m^2 whilst the top and second deck, rear pen walls, had a side-wall area of 3.168 m^2.

Wall openings: Externally, each wall of the truck crate was perforated with 27 openings, and the trailer crate had 36 openings per wall. Pens on the upper deck of both the truck and trailer did not have side-wall ventilation openings. The openings were rectangular slots 650 mm long x 95 mm high, but with both ends curved to a diameter of 35 mm giving an area of 0.062 m^2 per slot.

The wall of each pen in the truck-crate pen had six ventilation openings (three on each side) giving a total ventilation opening of 0.372 m^2 per pen or 10.78% of the wall area for the bottom pen and upper two decks and 10.11% for the second pen above the deck.

The wall of each pen in the trailer also had six ventilation openings (three on each side), giving openings that were 10.91% of the wall area for the bottom and third deck front three pen walls, 11.80% for the top and second deck pen walls, 10.86% for the bottom and third deck front three pen walls and 11.74% for the rearmost pens.

Effluent management: The floor of the bottom deck of both the truck and trailer crates was covered with a steel mesh that allowed effluent to drain directly into a shallow tank below the mesh (Figures 4 & 7). The floors of the upper three decks were made of close-fitting solid aluminium with channels and ducting that allowed effluent and rainwater to drain down to the tank below the bottom deck; the floors, when in place, were essentially water-tight. During the study, the effluent was drained from the holding tank underneath the bottom deck, by the driver, before or after each journey.

Stocking densities: The two larger piggeries used in the current study supplied roughly the same number of pigs (220 ± 20), of similar weights (90 kg ± 10 kg), weekly to the abattoir making stocking densities comparable week-by-week.

At the commencement of each journey the driver checked the total number of pigs that were to be transported to ensure that they could all be accommodated on the bottom two decks of the truck and trailer. During the study, the standard stocking density for all of the pens in the truck stock-crate was 14 pigs per pen and 15 pigs in the trailer stock-crate, giving a total load of 204 pigs. When loads exceeded

204 pigs or when, during hot weather the driver had reduced the pen number by two pigs per pen, the extra pigs were loaded on the rear pen of the third deck of the trailer.

From time to time the driver was required to pick up other stock, such as sheep or cattle, before the pigs were delivered to the abattoir; data from such journeys was not included in the study records.

The driver and journeys used in the study

The driver: The same driver was used throughout the study. He was considered to be one of the most careful and considerate drivers employed by the firm and had decades of experience as a stock-truck driver. An electric prodder was used occasionally by the driver, as needed, during both loading and unloading procedures.

After the author and driver placed the camera and data loggers, as needed, into their respective holders at the beginning of each journey, the driver was responsible for recording the times that the truck commenced its journey, the time that the truck stopped and restarted during the journey and the timing of the unloading at the abattoir. The driver was also responsible for starting the camera at the beginning of the journeys or during journeys as the particular phase of the study required.

The journeys: Pigs were loaded from the same piggery at Christchurch on the same day each week and driven south (the ‘southbound journey’) to the abattoir at Timaru that had provided the pre-study mortality records. After being unloaded at the abattoir the vehicle then travelled south, empty, to an overnight stopover at Palmerston. At 6.30 am the next morning the empty truck was driven to the second piggery in Dunedin to pick up another load of pigs for the abattoir before returning north (the ‘northbound journey’).

Each week the northbound journey was interrupted after about an hour, at Palmerston, to pick up another small load of pigs from a third farm. The pigs from the second and third farms were not mixed.

The southbound journey: The truck and trailer arrived at the farm at approximately 7.30 am every week. As soon as the vehicle was seen to enter the farm gate the pigs were moved from their sawdust-bedded barn, where all of the pigs were cohabiting, to a large concrete yard outside the barn. The movement was conducted in a leisurely manner by a group of four staff who used boards to direct the pigs and used a minimum of vocal or physical encouragement.

They were then herded into an assembly area adjacent to the loading ramp, with all of the barns used being within 50 m of the assembly area. Whilst the vehicle was being aligned with the loading ramp small groups of pigs were moved to a holding pen at the end of the loading ramp and tattooed on their rumps with the farm’s cypher using a ‘slap-tattoo’.

As soon as the truck had been aligned the driver checked that all of the internal gates and moveable floors were appropriately set up and assisted the author to put the loggers and camera in place as was needed for the different phases of the study. Approximately 25 minutes elapsed from the time that the pigs left their barn to the time that the first pigs entered the vehicle. The loading time from the time that the first pigs left the tattooing pen until the last pigs were loaded was approximately 50 minutes.

The northbound journey – the second farm: The truck and trailer were parked in a lay-by, approximately 0.5 km from the farm, before being loaded. The data loggers and camera were already in place and functioning when the vehicle reached the lay-by; the loggers were not switched off over-night.

On the farm, the pigs to be slaughtered (that had been marked for slaughter the night before their transport), were separated from their smaller cohort members and moved from their steel mesh floored pens. They were, tattooed by ‘slap-tattoo’, mixed with slaughter-weight pigs from other pens and then loaded on to a farm truck which took them to the lay-by. The farm truck was backed up to the rear of the transport vehicle’s trailer and the pigs were then moved from one vehicle to the other. The pigs were loaded onto the second deck first and the lowest deck last, a process that meant that the pigs on the bottom deck were not shut into pens but had free access throughout the bottom deck.

From the time the pigs first left their pens, in the farm, to the completion of loading on to the transport vehicle was between two and a half and three hours, with the truck-to-truck loading time averaging 80 minutes. The truck, after having been loaded, was then driven to a stopover point at Palmerston. This was approximately an hour’s travel from the second farm. Pigs from the third farm were loaded onto the trailer at this stop.

The northbound journey – the third farm: The process used to load the pigs at the third farm and to load those pigs onto the transport trailer at the stopover, was similar to that used at the second farm (i.e. truck-to-trailer transfer). The third farm was small leading to a small number of pigs being loaded and numbers varied considerably each week.

It should be noted that the genetics of the pigs were very similar on all three farms and that all three farms used automated, dry-feed, feeding systems that were switched off the night before the load-out, ensuring that the pigs had empty stomachs during transport. Details from the third farm were not used for the study.

Physical characteristics of the journeys: The southbound journey took an average of three hours 40 minutes, travelled through nine townships and covered approximately 165 km of flat countryside. The northbound journey averaged six hours 30 minutes, travelled through six townships, covered approximately 200 km and involved travelling over hilly country that had sections that were steep, with a gradient of up to 12% (Automobile Association, NZ). All the roads travelled on were sealed.

The driver made ‘comfort’ stops on each trip at the same locations each week. During these stops, recorded as ‘stationary periods’, he parked the truck and switched off its engine before visually checking the animals on board. When the truck was parked during these stationary periods the driver used whatever shelter was available for the protection of the pigs from the sun or wind.

The southbound journey usually involved a single comfort stop, though occasionally that stop was not used, and the truck travelled directly from the farm to the abattoir. The northbound journey usually involved two stops, one at Palmerston and the second (lunch-break) at Maheno, but occasionally a third stop was required at Oamaru before the truck arrived at the abattoir

Monitoring equipment used in the study

The camera: During the study a video camera (GoPro Hero 4, Silver Edition with extension battery providing a battery life of two hours) was mounted in a protective frame attached to the centre of the front wall of the bottom front pen at the pigs’ head height (Figure 7). The camera was able to film the pigs entering the trailer and moving to the bottom front pen; it also recorded the pigs in the pen after the pen gate had been closed. When the monitoring of the pigs during the ‘comfort stops’ was required, the camera was switched on from outside the vehicle with a Bluetooth-connected remote that was operated by the driver.

For most of the video footage obtained during the study, the camera was switched on immediately before the pigs were loaded at the first farm. It was used to monitor the pigs' behavior during loading, during the first stationary period, or during the period between loading and the stationary period when the vehicle was moving.

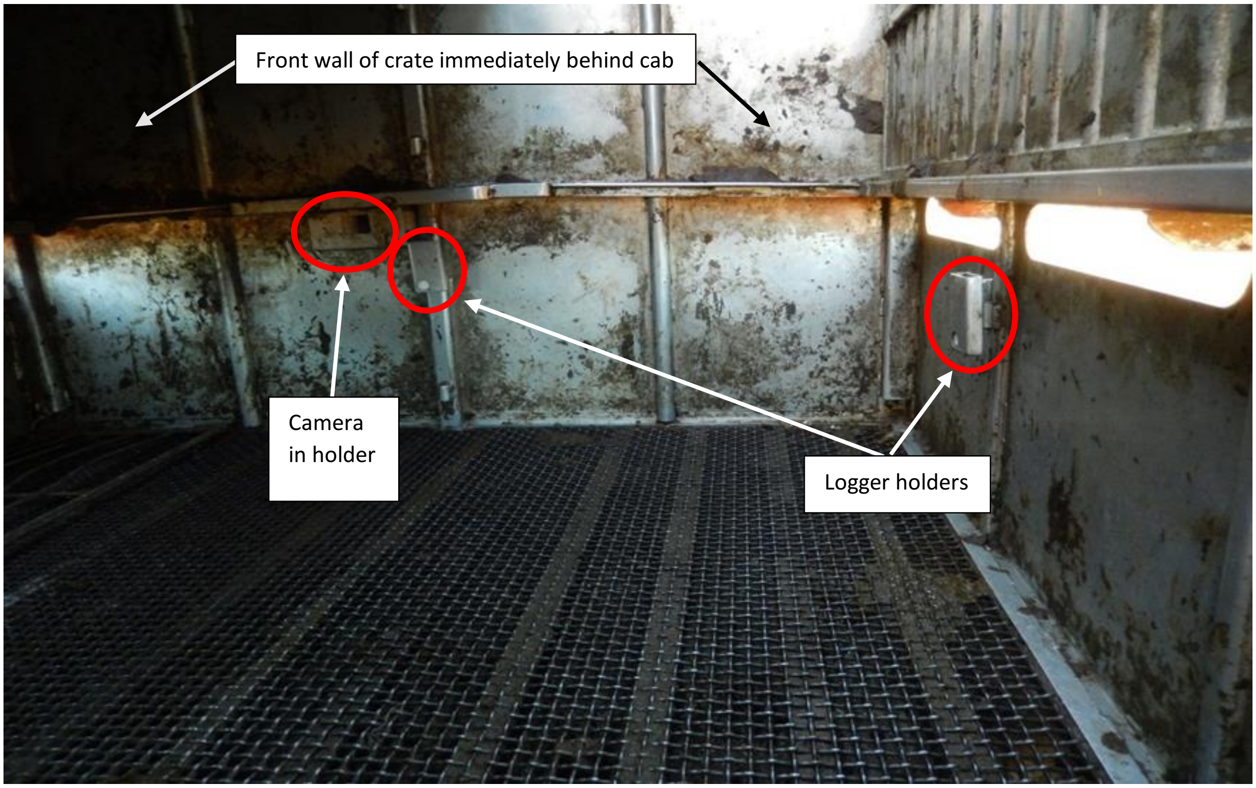


Figure 7: Position of the camera and logger-holders in the bottom front pen

Figure 8: Holder with logger in place on back wall of pen

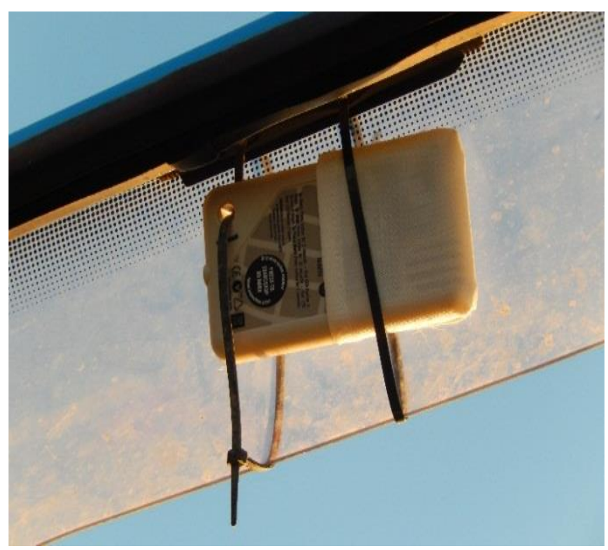


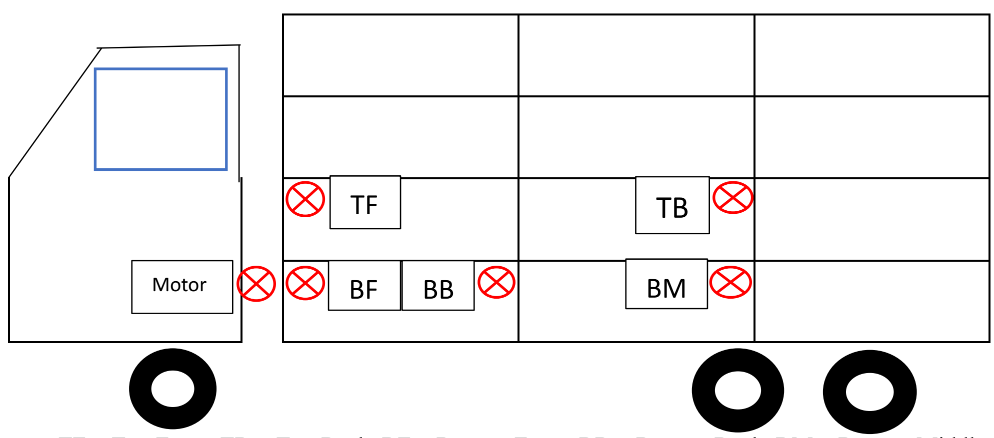
Figure 9: Logger attached to driver's wind shield

The data loggers: Temperature and humidity data were collected continuously using data loggers. The loggers used were Relative Humidity logger (953170ESCA), Temprecord International Ltd, supplied by Homersham Ltd. The temperature range of the loggers was -20° C to +50° C with an accuracy within 0.2° C over that range. The humidity range of the loggers was 0 to 100% with an accuracy, between 12% RH and 80% RH, within 3% and the time to reach 63% at 25° C and 1 m/sec airflow was eight seconds.

At a later phase of the study a Temprecord International Ltd, Multitrip Multi Use logger (953130BSGA), was used to monitor the temperature in the gap between the cab and the engine. That logger had a temperature range of -20° C to +50° C with an accuracy of 0.2° C over that range.

The loggers recorded date, time, temperature and humidity at two-minute intervals (Figure 13) and were mounted in light aluminium holders that had been attached to the walls of the pens. Only the sensors were exposed to the pen (Figure 8). Before being mounted in their holders the lower half of the loggers containing the sensor port, were enclosed in a linen sleeve (Figure 9). The sleeve was used to exclude any particulate matter that might enter the logger.

During the study, before the loggers were taken to the farm from which the pigs were to be transported, they were checked, and any previously recorded data was deleted. Once they were all ready, they were started in sequence with care being taken to complete the starting process as quickly as possible so that all of the loggers were starting at the same recorded time. Once they had all been started, the linen sleeve was put in place and the loggers were placed in a cardboard box for transport to the farm. This process was conducted in a heated office remote from the farm, therefore the loggers started recording conditions in that environment.



Where: TF = Top Front TB = Top Back BF = Bottom Front BB = Bottom Back BM = Bottom Middle

Figure 10: Position of loggers

On arrival at the farm the loggers remained in their box until the transport vehicle had been parked up against the farm’s loading ramp and the driver had opened the truck’s door. At that point the loggers were removed from their box and held until after the driver had left the cab. The two lower steps that led into the cab, were made from slotted extruded-metal that allowed air from outside the vehicle to circulate in the space surrounding the steps when the door was closed.

The ambient logger was then left on the lower of the two steps, exposed to the ambient conditions, until loading had been completed and the driver was about to leave the farm. At that point the logger was attached to the inside of the driver's window-windshield (Figure 9). Thus, the initial ambient recordings were taken at approximately 600 mm from the ground before being mounted approximately 2.5 m above the ground.

Once the ambient logger had been put in place on the step to the cab, the other loggers and camera were carried to the rear of the vehicle and taken through the length of the trailer and truck stock-crates, before being placed in their respective holders. The records of the journey times taken by the driver, were taken from the time that the ambient logger had been put in place on the truck's step as it was found that, for various reasons, the length of time that the truck arrived at the farm and the first pigs were run on to the truck, varied considerably.

During the phase of the study when the temperature in the gap between the cab and the stock-crate was being measured, a logger-support was attached to the engine's air cooler ducting. The position of the logger, when attached, was then at the level of the logger mounted inside the stock-crate on the front wall of the bottom front pen. This logger was mounted after the ambient logger had been put in place on the step to the cab and before the other loggers were taken to the back of the vehicle.

The data loggers were activated at the first farm (for the southbound trip) and switched off after the last pigs were unloaded at the abattoir at the end of the northbound journey.

Figure 11: **Logger-holder attached to a side-wall**

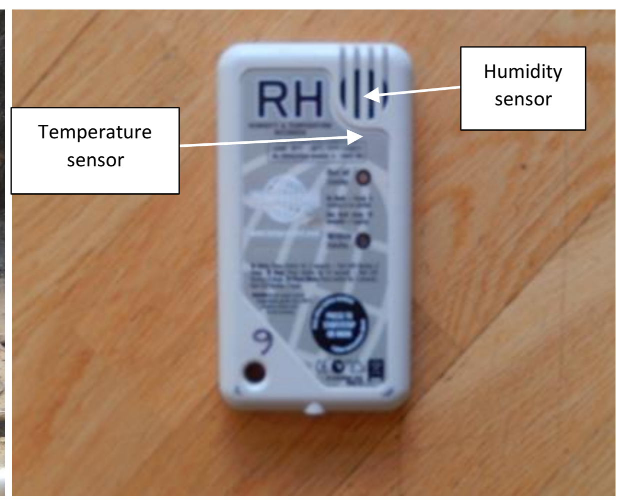


Figure 12: Location of the sensors within the data logger

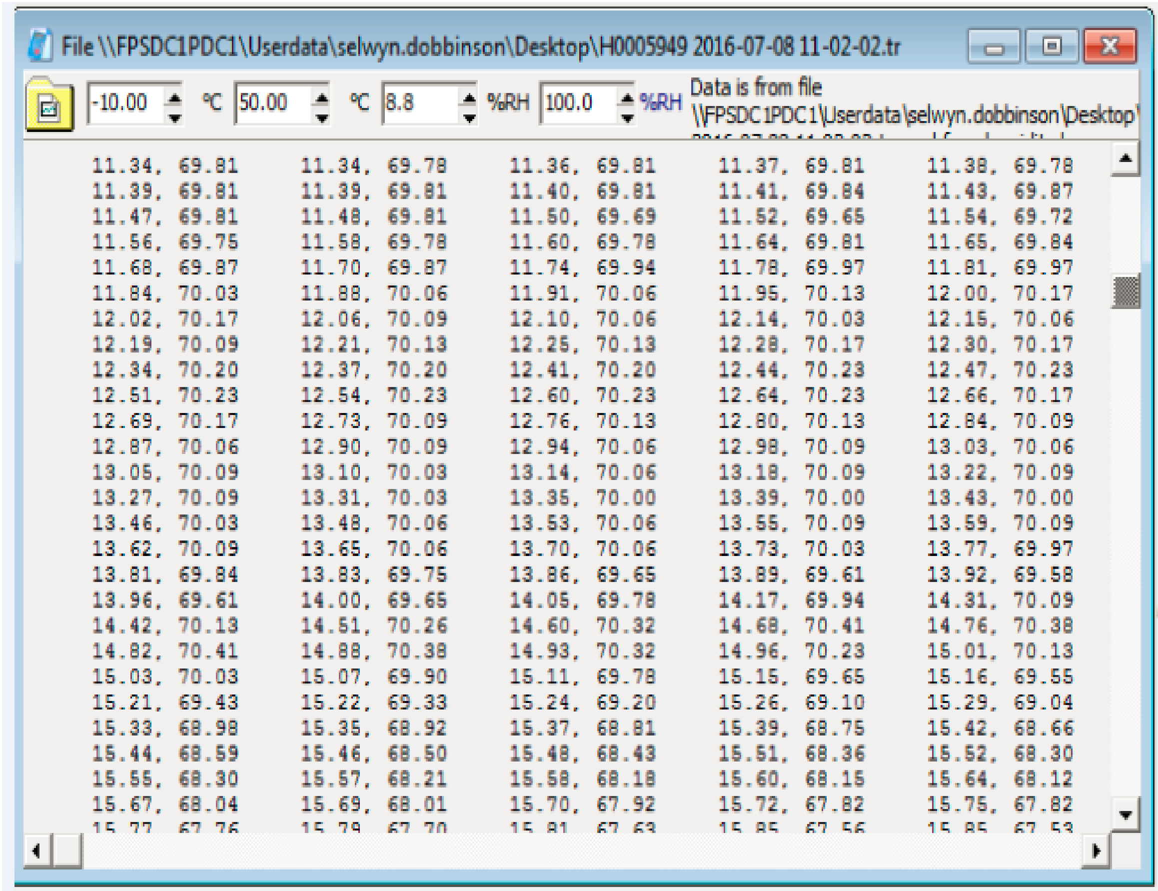


Figure 13: Initial screen downloaded from a data logger

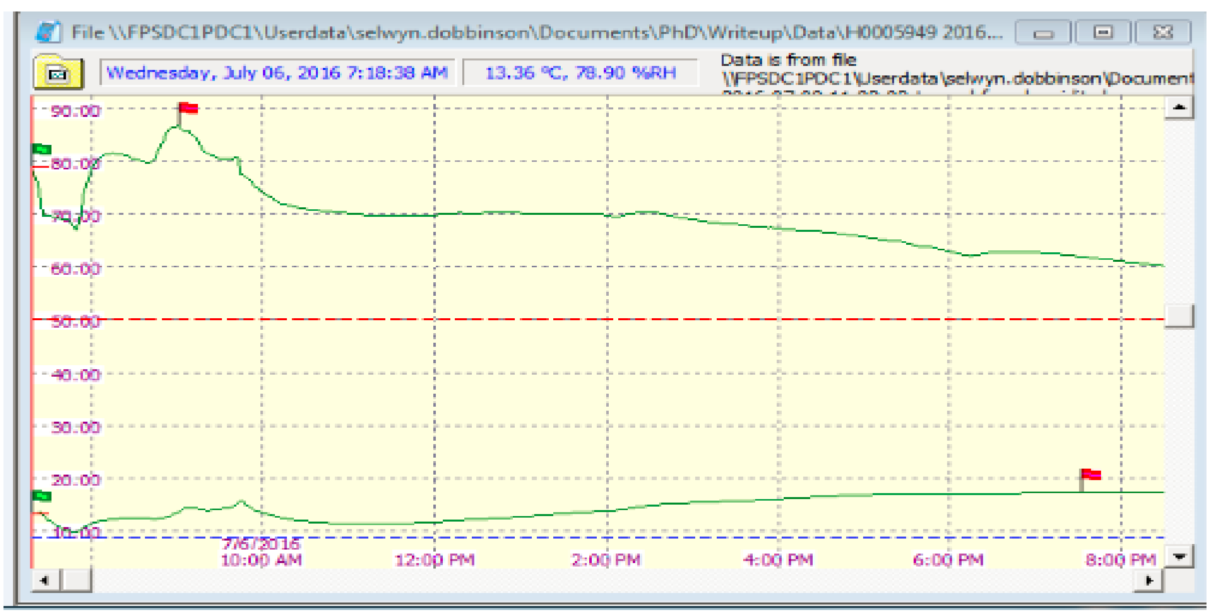


Figure 14: Graphic representation of the initial screen from the data logger

Sample Period	0:02:30		
Upper Temperature Limit	40.00		
Lower Temperature Limit	-5.00		
Mean Temperature	12.10		
Std Dev. Temperature	6.20		
Maximum Temperature	22.53		
Minimum Temperature	3.54		
Upper Humidity Limit	97.26		
Lower Humidity Limit	3.31		
Mean Humidity	77.87		
Std Dev. Humidity	77.87		
Maximum Humidity	94.60		
Minimum Humidity	52.44		
Date	Temperature	Humidity	
8/1/2018 07:21:24 AM	14.29	69.32	
8/1/2018 07:23:54 AM	14.17	69.04	
8/1/2018 07:26:24 AM	14.06	68.70	
8/1/2018 07:28:54 AM	13.97	68.39	
8/1/2018 07:31:24 AM	13.88	68.10	
8/1/2018 07:33:54 AM	13.80	67.78	
8/1/2018 07:36:24 AM	13.72	67.57	
8/1/2018 07:38:54 AM	13.65	67.31	
8/1/2018 07:41:24 AM	13.56	66.97	
8/1/2018 07:43:54 AM	13.80	63.70	
8/1/2018 07:46:24 AM	14.47	65.62	
8/1/2018 07:48:54 AM	13.25	66.53	
8/1/2018 07:51:24 AM	12.28	68.67	
8/1/2018 07:53:54 AM	11.60	71.09	
8/1/2018 07:56:24 AM	11.20	74.22	
8/1/2018 07:58:54 AM	10.94	77.35	
8/1/2018 08:01:24 AM	10.84	79.58	
8/1/2018 08:03:54 AM	10.86	81.49	
8/1/2018 08:06:24 AM	11.04	83.46	
8/1/2018 08:08:54 AM	11.74	85.59	
8/1/2018 08:11:24 AM	12.39	84.13	
8/1/2018 08:13:54 AM	12.91	84.22	
8/1/2018 08:16:24 AM	13.42	83.69	

Figure 15: **Excel format of the logger data produced by the Temprecord programme**

Date	Temp.	Amb. Humidity	THI	Temp.	BF Humidity	THI	Temp.	BM Humidity	THI	Temp.	TM Humidity	THI	Temp.	TF Humidity	THI	Temp.	Trailer Humidity	THI
5/4/2017 7:35	10.78	58.53	53	7.47	66.7	48	7.24	64.73	48	8.04	62.64	49	7.88	64.87	48	6.8	91.73	45
5/4/2017 7:37	10.86	56.9	53	7.51	66.86	48	7.23	64.73	48	7.98	62.58	49	7.87	65.43	48	6.71	91.51	45
5/4/2017 7:39	10.85	56.07	53	7.55	67.05	48	7.23	64.7	48	7.93	62.72	49	7.85	65.73	48	6.67	91.42	45
5/4/2017 7:41	10.97	56.9	53	7.57	66.67	48	7.21	64.53	48	7.89	63.05	49	7.82	66.18	48	6.67	91.54	45
5/4/2017 7:43	10.92	55.6	53	7.57	66.12	48	7.21	64.47	48	7.85	63.48	49	7.78	66.55	48	6.68	91.76	45
5/4/2017 7:45	11.02	57.29	53	7.57	66.31	48	7.21	64.53	48	7.8	63.76	48	7.76	66.55	48	6.78	91.88	45
5/4/2017 7:47	10.93	56.53	53	7.57	66.35	48	7.21	64.73	48	7.76	64.09	48	7.7	66.38	48	6.74	91.92	45
5/4/2017 7:49	10.89	57.7	53	7.57	66.67	48	7.21	64.93	47	7.71	64.49	48	7.66	67.11	48	6.82	92.01	45
5/4/2017 7:51	10.79	58.56	53	7.57	67.15	48	7.21	65.45	47	7.68	65.4	48	7.67	71.36	48	6.87	92.04	45
5/4/2017 7:53	10.62	58.65	53	7.57	67.6	48	7.21	65.86	47	7.68	68.99	48	7.73	73.67	48	6.93	92.14	45
5/4/2017 7:55	10.55	60.15	53	7.57	67.73	48	7.21	66.26	47	7.78	71.92	48	7.85	77.44	48	7.02	92.23	45
5/4/2017 7:57	10.45	60.08	52	7.55	68.21	48	7.23	66.46	47	7.94	72.59	48	8.16	86.35	48	7.14	92.29	45
5/4/2017 7:59	10.41	59.82	52	7.57	68.3	48	7.23	66.52	47	8.15	74.06	48	8.41	89.28	48	7.24	92.32	46

5/4/2017 8:01	10.32	59.79	52	7.57	68.27	48	7.21	66.52	47	8.43	77.85	48	8.77	91.08	48	7.34	92.35	46
5/4/2017 8:03	10.25	60.91	52	7.59	68.78	48	7.23	66.69	47	8.77	79.9	49	9.39	92.44	49	7.43	92.32	46
5/4/2017 8:05	10.24	60.05	52	7.63	68.92	48	7.24	66.81	47	9.11	80.86	49	9.85	93.01	50	7.54	92.42	46
5/4/2017 8:07	10.18	59.09	52	7.67	68.27	48	7.25	66.75	47	9.36	80.83	50	10.29	93.39	51	7.78	92.51	46
5/4/2017 8:09	10.14	58.59	52	7.74	68.12	48	7.29	66.55	47	9.57	79.58	50	10.84	93.92	52	8.03	92.57	47
5/4/2017 8:11	10.14	57.29	52	7.81	67.53	48	7.3	66.42	48	9.89	84.83	50	11.94	94.2	54	8.27	92.54	47
5/4/2017 8:13	10.12	57.62	52	7.89	67.79	48	7.35	66.09	48	10.19	85.95	51	12.26	94.37	54	8.25	92.48	47
5/4/2017 8:15	10.3	56.2	52	8.27	86.75	48	7.4	68.02	48	10.69	87.34	52	12.48	94.49	55	8.27	92.51	47
5/4/2017 8:17	10.74	54.43	53	10.12	93.99	50	7.62	70.22	48	11.02	86.69	52	12.89	94.68	55	8.3	92.48	47
5/4/2017 8:19	11.36	53.73	54	10.62	93.89	51	8.07	72.52	48	11.51	88.39	53	13.56	94.78	56	8.27	92.45	47
5/4/2017 8:21	11.76	50	54	10.91	93.83	52	8.62	75.74	49	12.01	88.96	54	13.99	94.87	57	8.29	92.42	47
5/4/2017 8:23	11.97	49.82	55	11.4	93.95	53	9.09	76.22	50	12.63	90.2	55	14.35	94.96	58	8.23	92.35	47
5/4/2017 8:25	11.9	49.59	55	12.01	94.11	54	9.61	76.99	50	13.03	90.23	56	14.79	95.03	59	8.19	92.26	47

Figure 16: Format of a table produced from the logger data with highlighted section indicating the point at which the vehicle was stopped.

As each logger was downloaded the initial screen showed the temperatures and humidities that were recorded for the whole journey. The programme next converted the data into a graphic form and then converted the data to an Excel format.

The author then converted the data from the loggers into two files, one for each journey (southbound and northbound) and THI calculations were added. The driver provided a list of the times of each section of the journeys and these were entered into the finished file for the trip by highlighting the stop and start times.

Figure 17: Pigs resting during a mid-journey stationary period

Figure 18: **A pig showing respiratory distress (open-mouth breathing)**

Table 1: **The length of the journeys and stationary periods during the study**

JOURNEY LENGTHS

	No.	Average	Range
South	96	3hr 40min.	3hr 15min. < 4hr 15min.
North	80	6hr 30min.	5hr 30min. < 7hr 25min.

Where No. = the number of journeys monitored

STATIONARY PERIODS

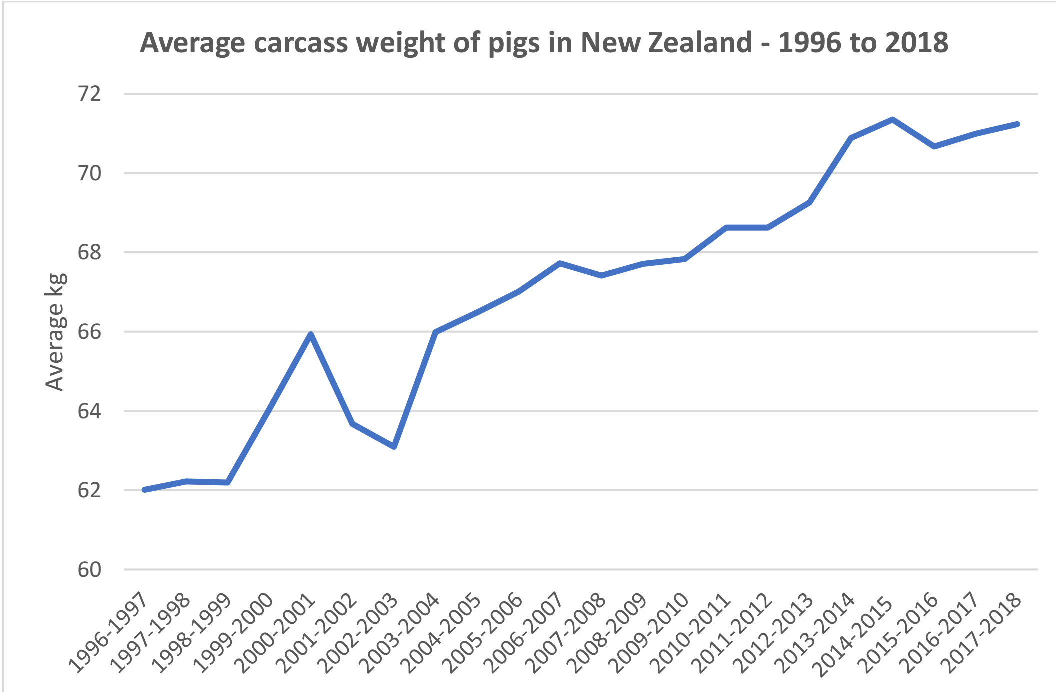
Loading

	No.	Average	Range
South	83	45min.	20min. < 75min.
North	70	78min.	55min. < 140min.

Mid-journey

	No.	Average	Range
South	80	30min.	15min. < 75min.
North	69	40min.	20min. < 75min.
	70	35min.	30min. < 45min.

Where No. = number of stationary periods recorded



Graph 1: Showing the increase in the size of pigs in New Zealand over the last 21 years.

DISCUSSION

Design features of stock-trucks and stock-crates in New Zealand that could impact on animal welfare

The most common livestock species transported in New Zealand in four-deck stock trucks are sheep, pigs, cattle and bobby calves. As a result, for economy, stock transport companies have required stock-crate designers to construct crates that can be used to transport any one of the species as needed. The result has been the widespread use of four deck stock-crates; with the exception of deer and poultry transporters, species-specific stock-crates, as are common in the Northern Hemisphere, are uncommon in New Zealand.

Over the last thirty years changes in New Zealand transport regulations have led to significant changes in the design of stock-trucks and stock-crates. Designers in New Zealand are required to avoid effluent escaping from stock-transport vehicles (see INDUSTRY CODE OF PRACTICE FOR THE MINIMISATION OF STOCK EFFLUENT SPILLAGE FROM TRUCKS ON ROADS; NEW ZEALAND STANDARD 5413:1993 AND REVIEWED IN 2004). Such requirements have led to a number of anomalous issues for the welfare of the livestock being transported.

Environmental regulations have also led to heavy diesel vehicles having to install catalytic converters, and road-user taxes relating to a vehicle's weight and length have led to changes in the type of truck used and the materials used in the construction of stock-crates.

Vehicle length: Because of the winding roads that are frequent in New Zealand, the length of vehicles is restricted; a further restriction is the total weight of the vehicle that is permitted. To accommodate the restrictions, and to ensure that transport is as economical as possible, the majority of livestock transport operators use a trailer that is towed behind a truck. Unlike countries such as Australia, vehicles in New Zealand are only permitted to tow a single trailer (called a 'B train').

It could be expected that the airflows and temperatures recorded in the New Zealand-style livestock transport vehicles would be different to those recorded in the longer, non-articulated vehicles used in North America and Europe. Whilst a number of studies reported the use of trailers, the dimensions of the vehicles were not always recorded, raising the question of how comparable the results would be for New Zealand conditions.

Heat from the engine and catalytic converter: To accommodate the restriction in the total length and weight of vehicles, the use of cab-over-engine trucks has become the norm for livestock transporters in New Zealand. When compared with the trucks that are used overseas (particularly those in North America) that have the motors extending out in front of the cab, the use of COE trucks has led to a potential difference in the amount of heat from the motor that impacts on the adjacent stock-crate.

Some of the heat from the engine block and the catalytic converter (hereafter called 'motor heat') will rise up the gap between the cab and the front wall of the crate in COE vehicles, heating the front wall of the stock-crate. The aluminium engine block dissipates heat by convection to the surrounding air so that, being situated underneath the cab, the bulk of heat arising from it could be expected to rise up the gap between the cab and the crate even when the vehicle was stationary. When the vehicle is moving, airflows underneath a vehicle could be expected to be turbulent due to the number of protrusions, and, with the airflows around the sides of the stock-crate could be expected to dissipate much of the heat (Gilkeson *et al*., 2009) thereby reducing the impact that motor heat has on animals in the stock-crate.

Heat from the catalytic converter (Figure 5), which begins to function at temperatures between 200 to 300^{o} C and operates at temperatures between 650 to 870^{o} C (Wikipedia), could be expected to contribute to the heat in the gap. As a result, the temperatures in the front pens of the crate could be expected to be influenced by the combined temperatures emanating from the truck's motor and catalytic converter.

Despite the number of references in the literature, that note that the bottom front pen in a stock-crate was the pen most prone to heat-stress problems, only one reference could be found (Brown *et al*., 2011) that noted the possibility that heat from the vehicle's motor might contribute to heat-stress within a stock-crate. No references could be found that looked at evaluating the potential problem. None of the references cited, that looked at ways to modify a stock-crate's environment with fans, sprinklers or misting, commented on the impact that the modifications might have on the contribution of heat in the bottom front pen resulting from the pen's proximity to the motor heat source. It would appear that the current study is the first to address the issue.

Ventilation within the stock-crate: The requirement that effluent from stock-trucks must be contained on the vehicles has led to changes in the design of the wall cladding of stock-crates. To minimise the weight of the loaded vehicle, aluminium or fibreglass wall cladding has become the norm. As a means to provide ventilation for the livestock being carried, openings have been made in the otherwise solid walls; the result has been the wide range of wall opening designs that are currently being used in New Zealand. Many New Zealand stock-crates have small wall openings at the level of the bottom deck for the purpose of dissipating any noxious gases emanating from the effluent tank. No attempt was made during the study to measure any noxious gases emanating from the effluent tank situated below the floor of the bottom deck.

Unlike the severe winters that many of the Northern Hemisphere countries experience, New Zealand has a temperate climate with relatively mild winters and hot summers. Stock-crate designs in New Zealand have therefore been focused on trying to get adequate ventilation for the summer months whilst ensuring that the wall openings are not so large that they create undue chilling of the animals in the winter. To ensure that the stock-crates are as well ventilated as possible, the top of the crates are not provided with a solid roof. In the Northern Hemisphere the majority of stock-transport vehicles have a solid roof over the top deck that, whilst protecting the animals from rain and snow, reduce the ventilation within the crates.

When the weather is hot the solid ceiling provided for in the uppermost pens (the third deck from the road) in New Zealand is generally not used by drivers. To provide shade for the stock on the upper deck a mesh cover can be stretched across the top of the stock-crate, however, because of the inconvenience, drivers tend to leave the animals on the upper deck fully exposed to the weather. The mesh cover or the lack of a ceiling would provide better air flows across the upper deck but would have a minimal effect on the environment in the lower decks.

A majority of the stock-transport vehicles used in the Northern Hemisphere are provided with the means to close off wall openings (called 'Boarding') (Figures 1 & 2) to prevent the animals becoming chilled during winter months. When the wall openings are closed off, ventilation within the stock-crates is compromised, leading to the need for mechanical ventilation systems to be installed.

Features such as the optimum size of wall openings in stock-crates are still unclear and largely based on personal preference as opposed to science-based decision making (Nigel Gordon, Nationwide Stockcrates, Tauranga, 2015). The NEW ZEALAND LIVESTOCK TRANSPORT ASSURANCE GUIDELINES (2013) suggest that wall openings should be '*a continuous opening on external walls*' and that they are required to be no larger than 100 mm deep.

Extrapolating guidelines from the literature or overseas experience is difficult because the climate in those countries that have undertaken appropriate studies, differs from the climate in New Zealand. Much more work needs to be undertaken to determine the most appropriate wall opening dimensions that will ensure good air quality inside stock-crates and yet meet environmental regulations.

Stocking density: At the commencement of the study it was calculated that having 14 pigs in each pen, the average stocking density would be 0.415 m^2/pig or 217 kg/m^2. There is variation in the recommended stocking densities in the literature however it was considered that such a density, whilst low, gave fewer pigs/m^2 than the EU recommendation of 235 kg/m^2. Whilst the Fitzgerald *et al*. (2009) study was based on heavier pigs than are typical in New Zealand (average 115kg compared with an average of 90kg), they calculated that at 226kg/m^2 there could be one and a half dead pigs per trailer load. This suggests that the stocking density used in the current study may have been marginal.

The individual weight of pigs is not available at the time of loading so that stocking densities are normally calculated by the number of pigs per pen. Since the total number of pigs that were to be transported each week would vary, the driver was instructed to ensure that the maximum number of pigs per pen was to be 15, which would lead to a maximum stocking density of 242 kg/m^2 during the study. It was the driver's practice to reduce the stocking densities during very hot weather (temperatures above 30^o C) by reducing pen numbers to twelve pigs per pen leading to a minimum stocking density of 194 kg/m^2, conversely, he would increase the number of pigs per pen by up to two during very cold weather in the winter months.

Ceiling height: From the literature cited and personal observation, four tier stock-crates are uncommon in the Northern Hemisphere, with two and three tier crates being the norm. The number of decks in a stock-crate impacts on the head-room available to the animals and thereby the amount of airspace above them. Ventilation and air quality are therefore affected by the number of decks in a stock-crate.

Visser K. (2014) noted that compartment heights within which animals are transported are necessary for adequate temperature regulation and removal of noxious gases. Warriss (1998b) stated that adequate space above the heads of animals is required to ensure that potentially noxious gasses such as carbon dioxide can be kept at acceptably low concentrations.

No regulations could be found in the literature to indicate the optimum head room for pigs but, considering the variability in the size of individual animals and the projected increase in the size of pigs in the future, 30 to 40 mm would seem to create a welfare concern for some baconer pigs and culled adult pigs, transported in New Zealand. The NEW ZEALAND LIVESTOCK TRANSPORT ASSURANCE GUIDELINES (2013) state '*Animals should have enough room overhead to give them sufficient air when the vehicle is not moving*', a statement that is not helpful for the designers of stock-crates.

The impact of pen height in Randall & Patel's (1994), model was not clearly described. Randall & Patel's model, in common with the majority of studies on stock-crate ventilation, used a pen height of 1 m; in 3-deck trucks the standard height would be 900 mm. They calculated that doubling the height of an aluminium-clad pen would reduce the pen temperature by 0.5° C; no impact on humidity was reported. However, they did not indicate whether their calculations included doubling the wall opening height as well.

It would appear that comparing the temperature, humidity and airflows between vehicles with different numbers of decks, could be misleading. The majority of the transport studies cited, that used flat-deck vehicles, had either two or three decks with none of the references using vehicles of similar design to the vehicle used in the current study. Many of the studies conducted in Canada or the USA used pot-bellied vehicles that were either articulated or had the cab directly attached to the stock-crate. Because of the configuration of the decks in a pot-bellied vehicle, and the pattern of the wall openings, it would appear that data collected relating to the environment within the pens may not be applicable to New Zealand-style vehicles. Ellis & Ritter (2005) commented that improvements in trailer design should include varying the ventilation openings (size, shape and position) along the trailer side to produce the required ventilation rate to keep air velocity and other environmental conditions within comfortable ranges for the pig.

The impact of the size of the animals: In the past thirty years the size of both pigs (Graph 1) and sheep have increased, however, the dimensions and layout of stock-crates have not changed over time. Ministry for Primary Industries (MPI) inspectors, when focused on animal welfare, are finding significant breaches with relation to animals suffering from abrasions caused by animals rubbing against overhead protrusions during transport (Richard Wild, Animal Welfare Manager, MPI, 2017).

Because of the legal height restrictions of vehicles in New Zealand the standard vehicles used for stock transport have their lowest deck approximately 1.2 m above the road surface resulting in the maximum height of pens, in a 4-deck crate, being between 750 to 800 mm. The dimensions and layout of stock-crates that are in common use in New Zealand, were set during a period when the pig industry marketed porker (50 to 60 kg live weight) pigs and adult sheep were also smaller than at the present time.

At the time of the study the preferred pig market weights was between 90 to 100 kg live weight and, in line with overseas trends, are likely to get heavier in the future as a result of the better economy gained when processing larger carcasses (Lynden Glass, CEO, Freshpork NZ, 2018). It would appear that future transport regulations in New Zealand will need to 'future-proof' the designs of stock-crates to accommodate the transport of larger animals.

In Australia and the USA, pigs are marketed at up to 120 kg compared with the 90 to 100 kg pigs in New Zealand, the heavier and therefore taller and bulkier pigs would take up more pen-volume. As Gilkeson *et al*., (2009) noted, air flows are impeded by the bodies of the pigs. The taller and bulkier pigs that are transported overseas would therefore be expected to obstruct air flows to a greater extent than the smaller New Zealand pigs. It would therefore appear that stocking densities that relate to the cubic dimensions of the pens in which the pigs are transported, would be more appropriate where stress levels are being compared.

The measurement of ambient conditions

A variety of methods for the measurement of ambient conditions have been used in the transport studies that have been cited. Several authors used data collected from the nearest weather stations (Xiong *et al*., 2015; Fox *et al*., 2014; Kephart *et al*., 2014; Nannoni *et al*., 2014; Fitzgerald *et al*., 2009; Haley *et al*., 2008b) whilst others attached loggers to the side-mirrors (Brown *et al*., 2011) or the sidewall of the study vehicle (McGlone *et al*., 2014c; Fisher *et al*., 2004).

Because of the rapidly changing weather patterns in New Zealand it was felt that the measurement of the ambient conditions should be taken as close to the vehicle as possible. Attaching a logger to the sidewall of the stock-crate was not considered as it was felt that heat from inside the stock-crate would be conducted through the aluminium wall and thereby compromise the readings. The driver did not want a logger to be attached to a side-mirror because he used his mirrors for backing the truck and trailer up to the loading and unloading ramps and did not want his view to be obstructed. A further consideration was that the logger was enclosed in a linen sleeve that would have become wet in any rain, thereby influencing the humidity readings and possibly damaging the humidity sensor.

As a result, it was decided to attach the ambient logger underneath the windshield above the driver's door. It was considered that the six mm gap between the window and the logger's sensors would be sufficient to minimise any impact of heat from the cab affecting the recordings.

The ambient logger was not fixed in place until after all of the pigs had been loaded and immediately before the driver left the farm. From the time that the truck was in place against the loading ramp, the logger was placed on the bottom step leading to the cab. The step had an extruded metal, perforated surface, so that the logger was able to record the ambient conditions once the cab door was closed. Whilst it was considered that the position on the step would provide an accurate measurement of the ambient conditions at the start of the journey, some unexplained results were recorded at the beginning of some of the journeys, suggesting that the ambient data collected before the logger was attached to the windshield may not have been accurate.

Monitoring equipment used in the study

<u>The data loggers</u>: The location of recording devices in a stock truck, when pigs are present, poses some problems. Pigs are destructive, being curious by nature, and will investigate any object in their surroundings by chewing on them. Many previous studies have suspended recording devices from the

ceiling (Brown *et al.*, 2011, Lenkaitis *et al.*, 2007) or have used robust protection around the devices when they have been attached to the pen walls (Kettlewell *et al.*, 2001a).

The height of the bottom front pen, at 750 mm, was considered too low to attach the data loggers to the ceiling as the protrusion could have led to pigs being bruised during their movement within the pen. It was therefore not possible to attach a logger in a centrally located position within a pen.

To minimise the effect of the heat being conducted through the aluminium wall cladding, so that data more accurately reflected the temperature and humidity within the pen *adjacent* to the four walls, the holders used on the front and back walls were welded to the crate's support structures rather than the wall cladding (Figure 7 & 8). In an attempt to minimise the influence of heat conducted through the aluminium side-wall cladding, the side-wall holders were separated from the wall cladding by a 15 mm diameter 'post' (Figure 11).

The temperature sensor in the logger was located in a small recessed area immediately below the humidity-sensor port (Figure 12) so that all temperature measurements would be taken through the circular port in the holder or in close proximity to it.

The loggers were attached to fixed points around the pen, therefore measurements only recorded conditions at those points and did not record conditions in the centre of the pen. However, it was considered that because of the movement of the pigs during transport, airflows would be turbulent with the only major differences between the records taken by the loggers being caused by the sun or wind on the side walls or heat from the vehicle's motor.

Since the air circulating close to the side walls would be subject to the effect of exposure to the sun or wind and the front wall was exposed to heat from the vehicle's motor, it was thought, and later corroborated by mathematical modelling, that data recorded on the rear wall would give the best indication of the average temperature and humidity of the air within the pen.

Whilst pigs, from time to time, rubbed up against the logger holders or nuzzled the camera-holder they did not appear to be interested in them so that such contacts were brief, and the contacts would have a minimal impact on the temperatures or humidity being recorded.

Because it was necessary to enclose the humidity-sensor port in a linen sleeve care was taken that the sleeve did not become wet as this could have impacted on subsequent humidity readings. As a result, loggers were not put in place on rainy days. Despite this precaution, rain did occur during some of the journeys, but it appeared that the logger holders provided adequate protection for the sleeves.

The camera: Filming could be conducted at any point during a journey through the Bluetooth connection but during the winter months, when the pigs were being loaded, filming was restricted by the lack of daylight. Limited views of the area outside the stock-crate were available through the wall openings. These views were particularly valuable in determining the movement of the vehicle and thereby the exact point at which stationary periods commenced and ended (corroborating the driver's records). Sound effects recorded on the video were also able to be used to confirm the timing of events.

The video recorded the time that had elapsed, so that by collating the time elapsed with the driver's records of the timing of events, and the sounds recorded on the video, it was possible to accurately determine the THI at the time that respiratory distress first occurred.

Figures 17 and 18 show the level of clarity that was provided by the video camera. Of particular note is the saliva drooling from the open mouth of the pig in Figure 19. Such images indicated the way by which pigs managed heat-stress and gave the opportunity to accurately calculate the THI point at which heat-stress commenced.

Differences between the southbound and northbound journeys

Dietary influences: Both of the farms that were compared in the study used very similar feed ingredients, similarly balanced rations and similar feed delivery systems. Cronje (2005) pointed out that the content of a pig's diet and the length of the pre-journey fasting period can impact on the amount of heat produced by a pig and thereby the amount of transport stress. Because the farm dietary management practices were similar on both farms, it was considered that dietary considerations should not have impacted on the results of the study.

Loading - biosecurity: The loading procedure for the northbound journey was affected by the farm's biosecurity requirements. The farmer would not allow the truck and trailer to enter his property as the truck had previously visited the abattoir and other piggeries. As a result, the pigs were exposed to considerably more loading-stress than the pigs used for the southbound journey.

The layout of the farm providing pigs for the southbound journey ensured that the truck was separated from any areas to which pigs had access, and the layout ensured that the southbound pigs experienced minimal stress from the time they left their shelters to the time at which they were loaded onto the truck.

Loading -ramp angle: The design of the ramp and loading facilities for the southbound journey was designed to minimise the loading stresses at that farm by having a very long ramp (which affects the angle of the ramp when connected to the truck's trailer) and having the level of the bottom deck of the trailer level with the floor of the pen into which the pigs were assembled for loading. However, when the second deck was being loaded the angle of the ramp leading to the truck increased to greater than 20 degrees of inclination; if the third deck had been used the angle would have exceeded 40 degrees. As Temple Grandin (2002) pointed out, angles greater than 20 degrees are stressful to animals. Many countries, to reduce loading stress, are now using hydraulic lifts to ensure that animals are not required to climb steep ramps; such stress-related features were only mentioned in two of the studies cited.

The northbound pigs had no ramp to negotiate during the process of transferring them from the farm truck to the transport trailer, however, within the farm the pigs had had to negotiate a ramp for the loading onto the farm truck. The pigs were loaded onto the bottom and second deck of the farm truck so that when the transfer from the farm truck to the transport trailer occurred, the pigs moved from decks that were at the same level. As a result of the differences between the loading procedures at the two farms, it was considered that the loading for the northbound journey was more stressful than for the southbound journey.

Loading procedures: The physical and psychological stresses associated with the loading of the pigs on to the truck, at both farms, were very different. Grandin (2008 & 1980), stated that from an animal welfare, if not from a meat quality perspective, loading stresses should be minimised. The selection process used on the northbound farm led to pigs from different pens being combined into a group that would lead to significant hierarchical challenges amongst the pigs. It was anticipated that by measuring the scratches and bite-wounds on the carcasses, later in the study, the degree to which these differences in stress might be able to be estimated (Nannoni *et al*., 2014; Correa *et al*., 2010).

The number of pigs loaded at both farms were very similar but loading times differed. Averos *et al*. (2008) noted that the length of time that was taken to load a vehicle can be used as an indicator for the degree of stress that pigs experience during loading, which suggests that the northbound pigs may have suffered greater loading stress than the southbound pigs.

Stationary periods – mid-journey: The number and length of the mid-journey stationary periods differed between the two journeys. Few of the studies cited in the literature, had mid-journey stationary periods, focusing on the negative impact of stationary periods during those periods associated with loading and unloading. However, Xiong *et al*. (2015) showed that such stops resulted in a rapid increase in the temperature within stock-crates whilst Lenkaitis *et al*. (2007) showed that humidity dropped when a vehicle was moving and rose when the vehicle was stationary. These findings suggest that the differences between the mid-journey stationary periods may have impacted on the stress levels experienced by the pigs.

Length of the journeys: The distance travelled, the topography of the country traversed, the number of residential areas that the vehicle needed to negotiate and the time of day that the pigs were off-loaded at the abattoir, differed markedly between the two journeys.

Averos *et al*. (2008) noted that it was not the distance travelled but the duration of a journey, that impacted on the level of stress that animals experienced. In the literature, the significance of the impact that the duration of journeys has on stress levels varies. Some authors (Brown *et al*., 2012; Nielsen *et al*., 2011) reported that longer journeys were more stressful than shorter journeys whilst others (Faucitano, 2013; Averos *et al*., 2007) found the reverse to be true. The author believes that these differences may be due to the failure to report driver behaviour, type of vehicle used (pot-bellied versus flat-deck), the size and genetics of the pigs being transported, the diets and the use of chemical growth-enhancing chemicals, the topography of the journeys and the weather during the journeys.

In the current study care was taken to minimise such variables. By using the same driver and the same routes for the journeys, the author believes that the transport stress levels experienced by the pigs should have been very similar for each journey of the southbound and northbound trips but the journeys between the two farms would have been different.

Unloading: Because of the differences in the lengths of the two journeys (southbound/northbound) the ambient temperatures that occurred during the unloading stationary periods differed. Unloading at the end of the southbound journey was normally completed by 11.30 am whilst the northbound unloading was not normally completed until 2 pm. As a result, when compared with the southbound journeys, the northbound pigs were exposed to higher ambient temperatures during the latter part of their journeys.

Often, because of the lateness of the arrival of the northbound pigs at the abattoir, the pigs were held overnight in the lairage before being processed the next day.

CONCLUSIONS

Every effort was made to minimise the variables that occurred in the study. Despite that a wide range of variables that could not be managed were inherent in the study design. As a means to reduce the impact of potential temperature and humidity variables such as rain, wind, solar radiation, season, stock size, number and gender differences, the study was conducted over a three-year period. Of particular concern was the unexplained inconsistencies in the ambient temperature records suggesting that a better method needed to be used to measure ambient conditions.

The design of the vehicles used in the transport studies that have been cited, differed from the vehicles typically used in New Zealand. Features such as head-room and wall opening size could have impacted on the environment within pens making the conclusions that were reached in the literature, difficult to correlate with New Zealand transport conditions.

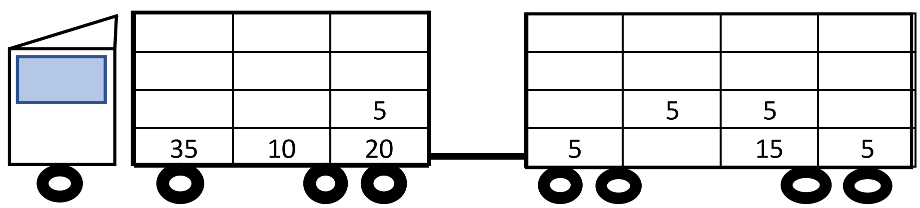
Chapter three

CONDITIONS WITHIN THE TRUCK'S STOCK-CRATES

The pre-study report

Between January 2008 and December 2011 the abattor that was used in the current study collected mortality data from all of the lines of pigs that were received at the lairage. Seven transport companies delivered pigs to the abattoir with all of the vehicles having similar COE drive units towing trailers, four-deck construction and pen layouts, principally only differing in the design of the wall openings. All of the trucks delivered 200 ± 20 pigs per week, using the lowest two decks though, on occasion some pigs were transported on the third deck of the trailers.

The yard staff at the abattoir recorded transport details that included the location where dead pigs were found, either in the stock-crates or within the lairage. One hundred and fifty seven pigs were found dead in the lairage pens and 34 were found in the truck or trailer.



Where: The numbers = the percentage (to the nearest whole figure) of DOA pigs found during 2008 – 2011

Figure 19: Showing the location of the DOA pigs found at the abattoir

A later study conducted between January 2010 and March 2012 was conducted to identify the seasonal pattern of the deaths.

Table 2: Number of pigs arriving dead at the abattoir, by month, during 2010 - 2012

J	F	M	A	M	J	J	A	S	O	N	D
7	7	12	3	8	9	12	4	3	14	5	7

Seasonal weather patterns during the study

The initial phase of the study focused on the environment within the bottom front pen of the truck's stock-crate. As Kettlewell *et al*. (2001a) stated, conditions within a stock-crate are influenced by the external conditions. The following table shows the average temperature within the bottom front pen during the loading of pigs for a southbound journey.

Table 3: Average temperatures within the bottom front pen over a two-year period from the time of loading to unloading

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Number of trips (n)		10	6	7	5	6	4	10	7	3	5	6	5
Mean Temperature (° C)		18.73	20.22	17.74	16.78	15.1	13.26	12.75	14.13	17.03	17.61	17.47	22.91
Range (° C)	Min	6.78	9.90	8.54	8.23	5.99	5.16	2.79	3.01	9.01	7.34	6.13	16.03
	Max	31.34	33.93	29.24	28.63	24.42	22.60	28.39	27.36	23.74	28.52	29.22	34.03
Number of occasions the upper critical temperature (25° C) was exceeded		6	4	3	1	1	0	2	1	0	3	3	4

Several authors (Haley *et al*., 2010; Averos *et al*., 2008) have noted that conditions within a stock-crate are influenced by ambient temperatures. The following table shows the average weather patterns for the region where the southbound journeys were conducted.

Table 4: Difference between the average monthly temperatures in Canterbury and those recorded in the bottom front pen during the study period, 2016-2018 (W. Thompson, NIWA Research Scientist)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Canterbury mean (° C)	16.9	17.0	15.0	11.6	9.0	6.7	5.9	7.1	9.3	11.1	13.2	15.9
BF pen mean (° C)	18.7	20.2	17.7	16.8	15.1	13.3	12.8	14.1	17.0	17.6	17.5	22.9
Difference (° C)	1.8	3.2	2.7	5.2	6.1	6.5	6.8	7.1	7.7	6.5	4.2	7.0

Table 5: Ambient temperatures and relative humidity in Canterbury over a ten-year period (Macara, 2016)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Temperature (° C)													
	Min	14.25	14.75	12.20	11.85	12.80	4.10	3.30	7.50	11.45	9.45	13.20	16.60
	Max	23.95	22.45	20.70	20.45	19.00	16.20	14.20	25.10	21.65	18.60	21.75	24.35
	Average	19.47	16.13	15.63	15.29	15.52	8.65	8.49	13.99	15.92	15.35	15.94	15.21
Mean Relative Humidity (%)													
	Min	49	49	56	50	46	47	56	43	41	61	58	61
	Max	76	83	84	76	70	72	77	75	74	85	83	71
	Average	66	68	72	61	61	64	68	54	55	77	74	56

The environment in the bottom front pen

Visual observations: The groups of 14 pigs that were loaded first had to traverse the maximum length of the truck and trailer. The video images showed the relatively slow progress of the first pigs to be loaded as they investigated the vehicle's environment pen by pen. Whilst the loading of the pigs during the southbound and northbound trips was different, the behaviour of the pigs held in the bottom front pen was similar.

Once they were shut in the pen (southbound journey), the pigs milled around randomly investigating the pen. During this period a few individuals would have brief, minor vocal and/or physical confrontations with other pigs in the pen. After a variable period, aggressive incidences diminished and some of the pigs laid down whilst others continued to stand, 'dog-sit' (sitting on their rump with front legs extended to raise the head and chest off the floor) or meandered around the pen.

Unless the loading process was prolonged the majority of the pigs would remain standing throughout the period during which they were being loaded. If the loading process was delayed some of the pigs would lie down in no observable pattern.

When the vehicle's motor was switched on many of the pigs showed a startled reaction with eyes dilated, heads raised and being moved from side to side; no vocal alarm was noted. As soon as the vehicle started moving the pigs lurched until they attained a stable stance and then swayed until they managed to find their balance. Soon after the vehicle started moving some of the pigs began to lie down or took a 'dog-sitting' position. Particularly in hotter weather, as the journey continued, most of the pigs would lie down. When the vehicle slowed and finally stopped at the commencement and during a stationary period, the pigs showed the same pattern of alertness followed by lying down.

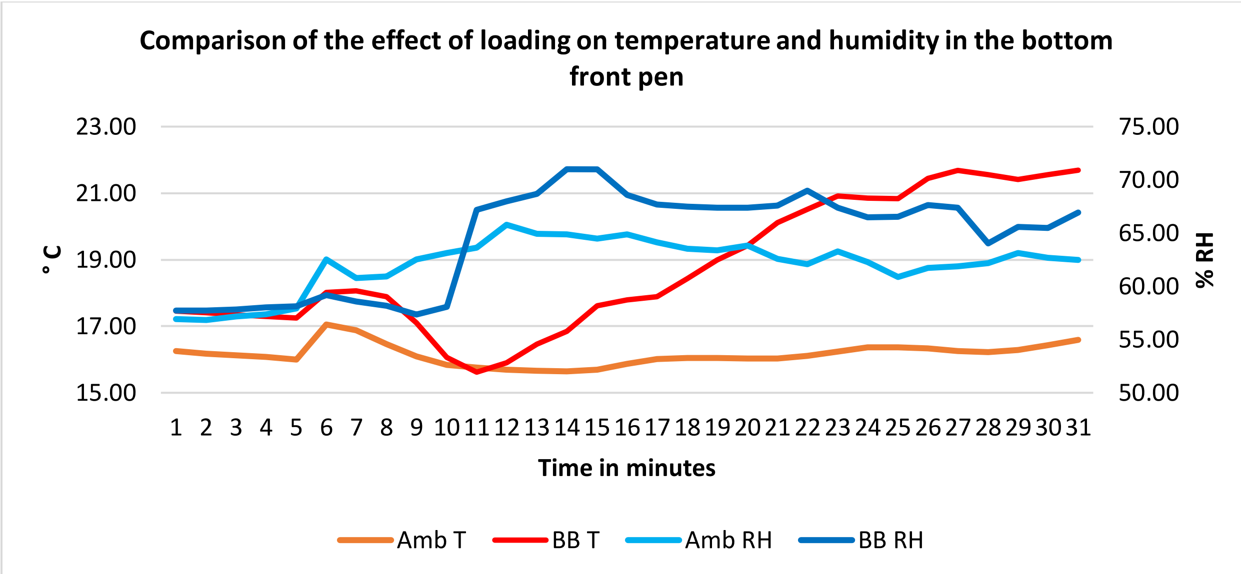
During northbound journeys the pigs on the lower deck were not penned in and were free to move from one pen to another throughout the journey. Overall, the pigs' behaviour followed the same pattern as for the southbound journey with movement being from one pen to another rather than being confined to an individual pen. Individual pigs appeared to establish a 'territory' soon after entering the stock-crate and tended to remain at the same location until they were being unloaded.

During both journeys, on a few occasions a small number of pigs would stand hyper-salivating, with their heads down, and an anxious expression. These events appeared unrelated to the environmental temperature and no vomiting was ever noted.

There was no evidence to suggest that pigs showed any preference to which wall of the pen they stood or laid against despite walls having widely differing temperatures. In the winter months when ambient temperatures were below 3^{o}C, after arrival in the pen pigs tended to huddle together initially, but after a variable period they showed a preference to stand or lie apart.

When THIs in the low 70s occurred, some individuals would start to breathe with their mouths open. This behaviour was preceded by a short period of panting (respiration rate of 120 breaths per minute). Once THIs reached 73 or greater, more than one pig could be seen with open-mouth breathing.

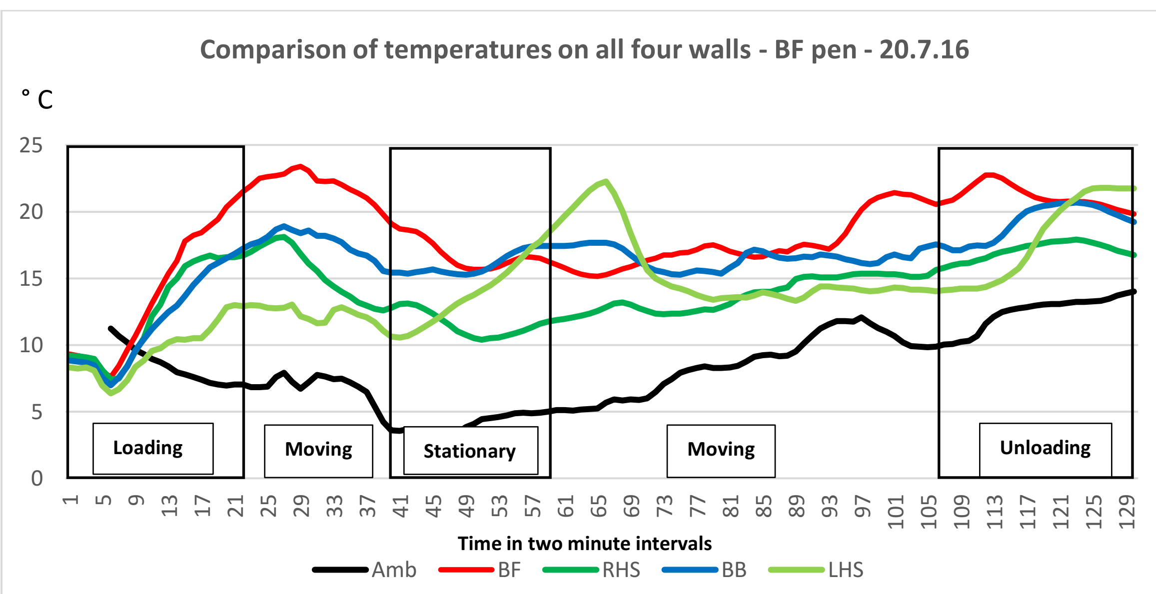
The pen environment during loading: Data loggers that recorded temperature and humidity were set to collect data at two-minute intervals throughout the study. Ambient temperature and humidity conditions remained steady over the loading period whilst the temperature and humidity in the pen both rose.



Where: Amb T = Ambient temperature; BB = the back wall of the pen; RH = Relative Humidity

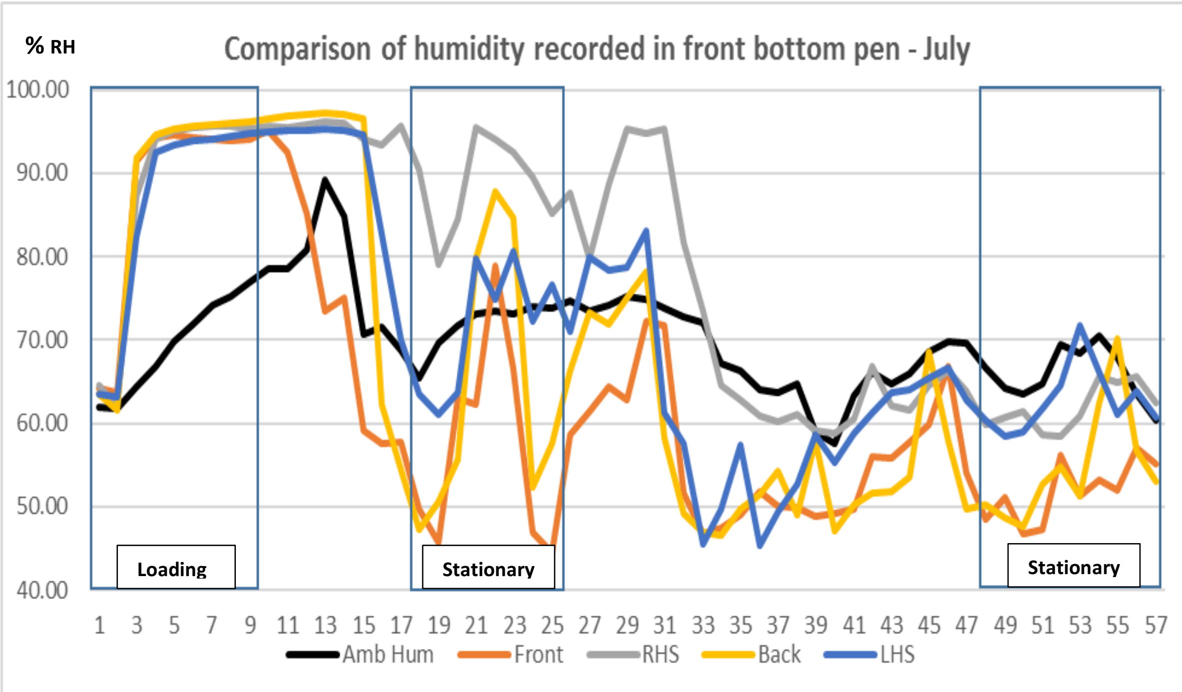
Graph 2: Comparison of the temperature and humidity rise during the loading of a single typical journey

<u>The changing of the bottom front pen environment during a journey</u>: At the beginning of the study temperature and humidity recordings were taken weekly for sixteen southbound and fourteen northbound journeys through March to July 2016.



Where: Amb = Ambient; BF = Bottom front wall; RHS = Righthand wall; BB = Back wall; LHS = Lefthand wall. NB: Right hand side of the vehicle was facing the sun. NB Wind affected the lefthand side wall at the beginning of the stationary period.

Graph 3: Showing temperature changes within the bottom front pen during a typical single journey



Graph 4: **Showing humidity changes within the bottom front pen during a typical single journey**

Heat map 1: Showing THI changes for the bottom front pen during a typical journey

Amb T °C	Front	RHS	Back	LHS
		January		
23.8	69	69	69	68
25.2	69	68	68	68
26.1	71	68	68	69
26.5	73	71	68	69
26.6	73	70	68	69
26.9	76	72	69	70
26.6	73	72	70	70
26.3	76	73	72	73
26.2	81	74	74	73
26.2	79	72	75	74
26.1	78	73	75	75
26.1	76	74	75	76
26.3	76	73	75	77
27.4	77	72	72	78
26.7	76	72	69	75
25.3	75	72	70	74
23.7	75	72	71	74
22.8	74	73	71	74
22.1	74	74	72	74
22.4	74	72	72	74
22.5	74	72	72	73
25.4	73	71	72	72
24.4	74	73	72	72
22.8	75	73	72	74
22.4	74	74	72	73
22.1	77	74	72	74
22.6	75	73	72	73
22.9	74	72	72	73
23.7	75	76	73	74
24.2	75	76	74	74
25.0	76	75	75	74
25.9	77	75	75	74
26.6	76	75	75	75
27.3	76	75	75	75
27.6	76	75	76	75
28.0	77	75	75	76
27.4	75	73	74	75
25.7	74	73	72	74
24.1	73	72	72	73
23.5	72	71	70	71
23.5	73	72	73	72
23.5	74	72	71	73
23.1	73	72	71	72
21.9	72	71	68	70

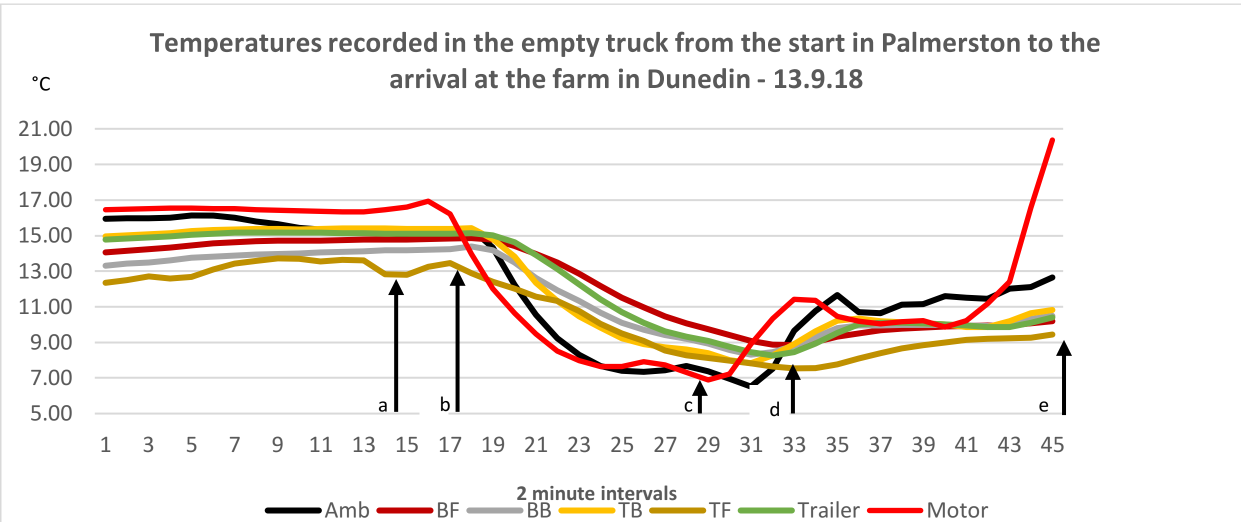
Note on the use of heat mapping: *Heat mapping is a simple method for processing large groups of numbers to visually show gradient changes within a data stream. The colours used for this chart vary from the highest THI recorded during the trip (red) to the lowest THI (blue). To produce this heat map recorded data intervals were reduced from one every two minutes to one every four minutes.*

Note 1: the shaded side of the vehicle was the LHS

Note 2: the boxed areas are periods when the vehicle was stationary; between the boxed areas the vehicle was moving

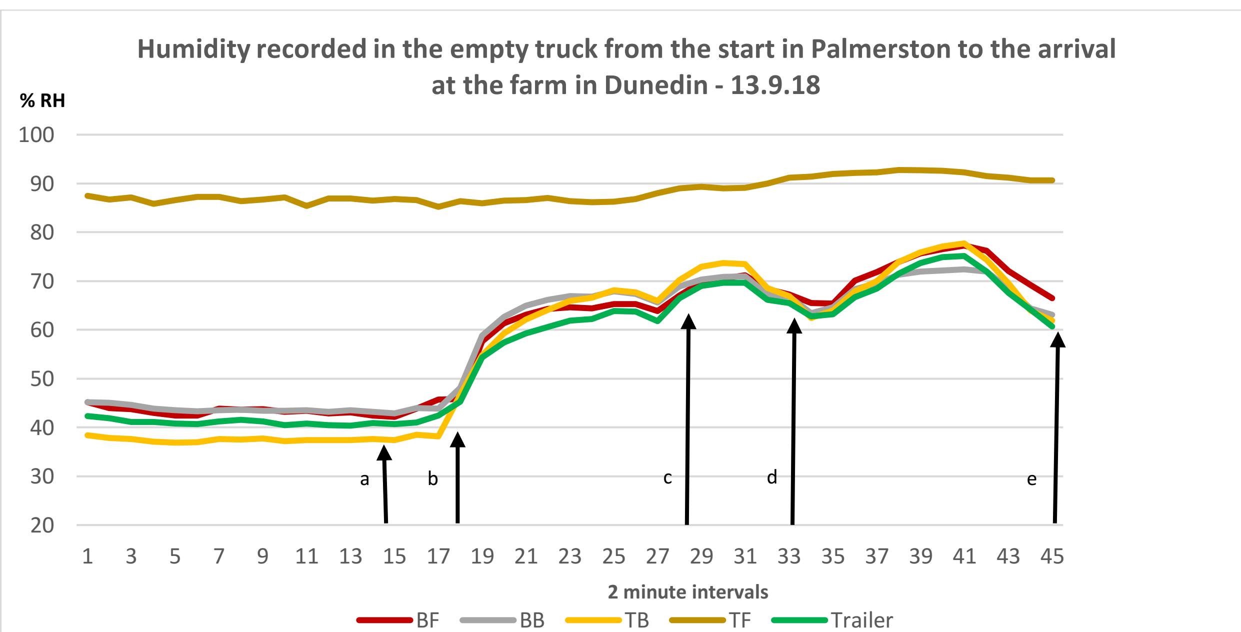
The difference between the environments in the bottom front pen and the three pens adjacent to it

<u>*The effect that heat from the truck's motor had when the truck was empty*</u>: The empty truck left the overnight lay-over every trip, at 6.30 am at the beginning of the northbound journey. After a period of up to five minutes 'warm-up' the truck drove south through the residential area of Palmerston and 20 minutes later it commenced the steep climb (< 12%) up the Kilmog, later climbing the steep Northern Motorway before descending through the residential area of Dunedin City. Twenty minutes after reaching the city it parked up outside the farm at 7.30 am after climbing the steep incline up the peninsular 'High Road'.



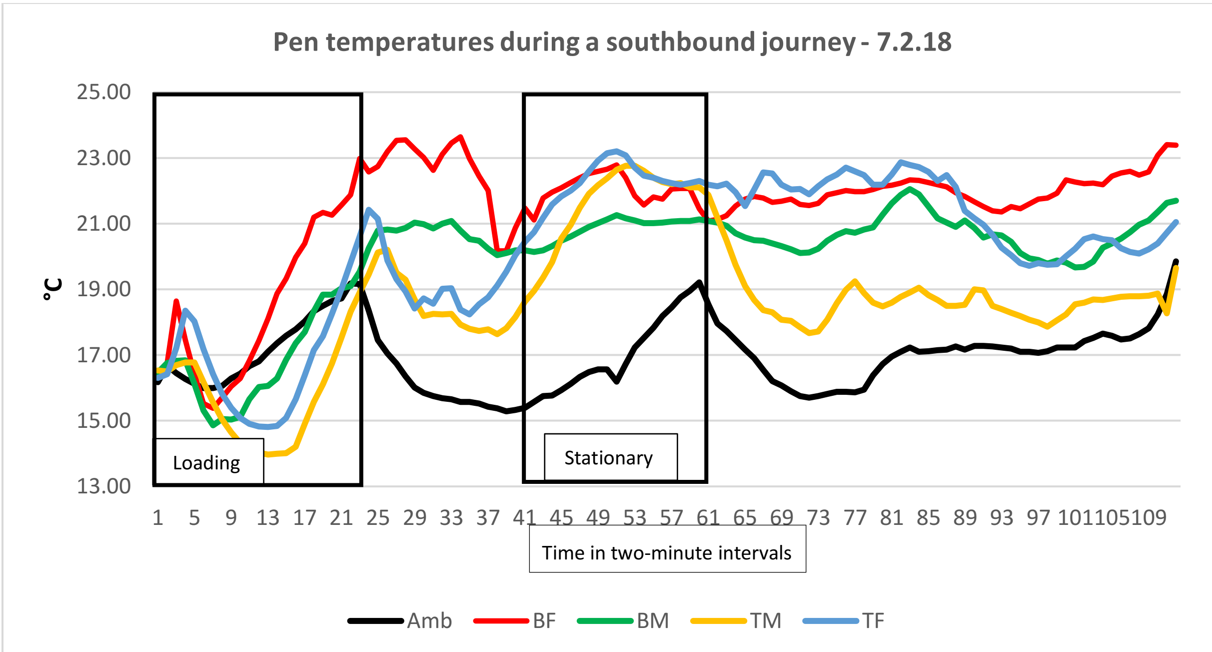
Where: a = motor starts b= journey starts c = first steep climb d = second steep climb e = arrival in Dunedin

Graph 5: Temperatures recorded in an empty truck at the start of a day's journey

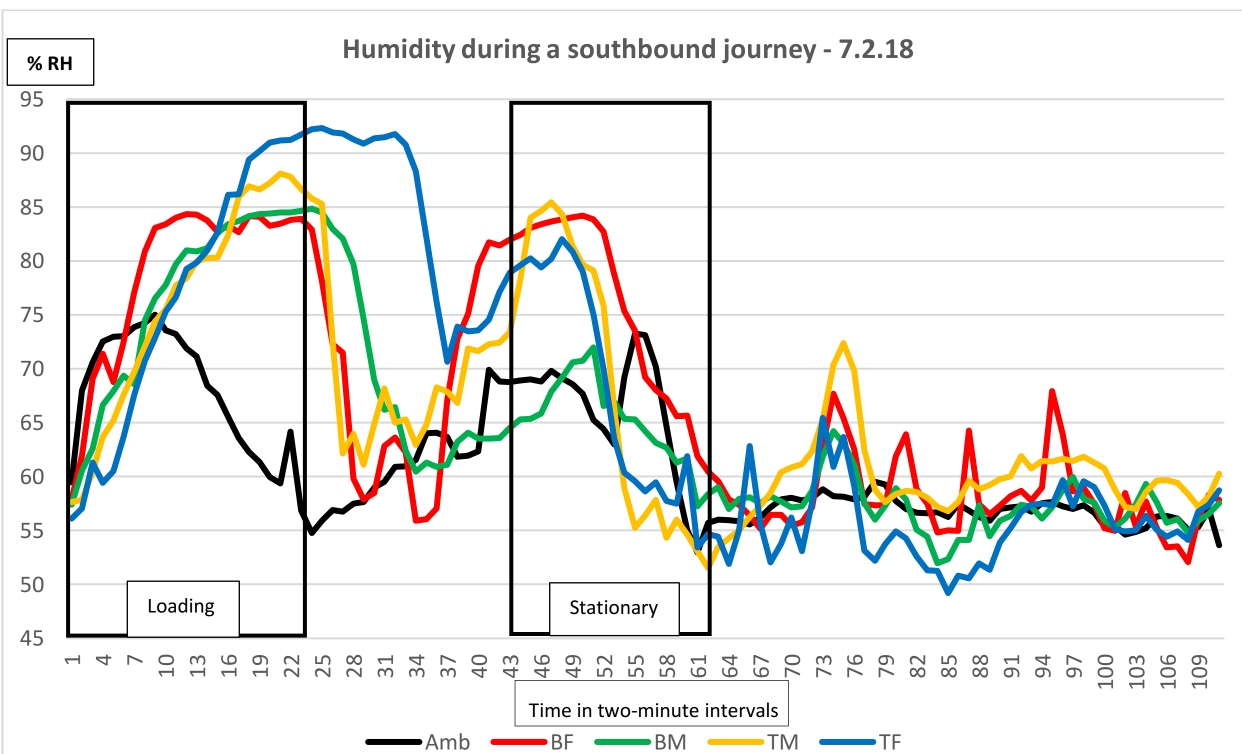


Graph 6: Humidity recorded in an empty truck at the start of a day's journey

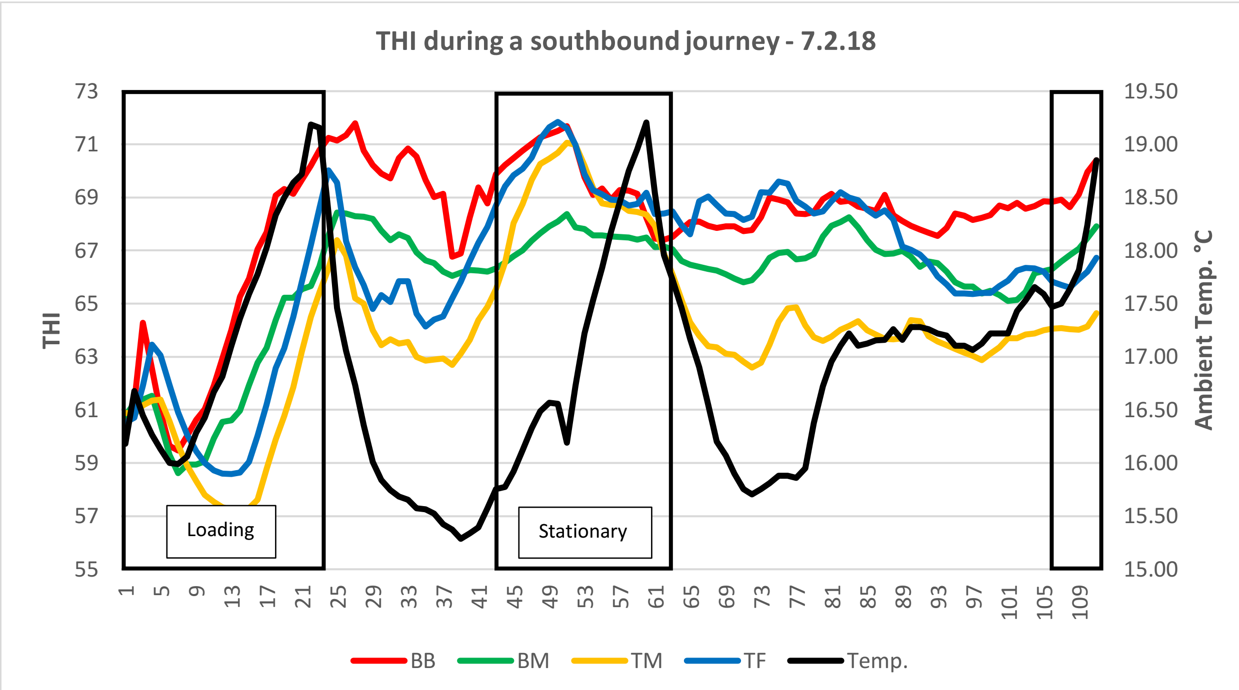
Comparison between temperature, humidity and THI during a southbound journey



Graph 7: Pen temperatures during a southbound journey



Graph 8: Pen humidity during a southbound journey



Graph 9: **Pen THI during a southbound journey**

Heat map 2: Comparison between THI, Relative Humidity and Temperature during a February journey

THI				Amb.	RH				Amb.	Temp.			
BF	BM	TM	TF	% RH	BF	BM	TM	TF	ºC	BF	BM	TM	TF
59	59	60	60	70.7	70.0	68.6	67.5	67.6	14.8	14.99	15.24	15.7	15.58
59	59	60	60	71.0	70.1	68.7	67.5	67.5	14.8	14.92	15.19	15.61	15.5
59	59	60	60	71.0	70.2	68.9	67.5	67.5	14.8	14.89	15.18	15.51	15.46
59	59	59	59	71.1	70.3	69.0	67.6	67.5	14.8	14.85	15.15	15.45	15.38
59	59	59	60	79.3	74.2	73.7	73.9	79.0	15.4	15.22	15.23	15.41	15.41
58	58	58	58	79.9	80.9	77.8	80.1	83.3	15.8	14.55	14.27	14.51	14.66
60	59	57	57	72.5	95.0	91.9	86.4	87.2	17.0	15.58	14.8	13.84	14.09
63	61	57	57	70.8	96.0	93.9	92.2	90.0	17.2	17.11	16.02	13.7	14.04
66	64	57	58	69.3	96.1	94.4	93.9	91.7	17.3	18.86	17.64	13.94	14.3
69	65	59	60	67.8	96.0	94.3	95.5	94.7	17.4	21.39	19.1	16.02	16.55
71	67	63	64	66.5	96.0	93.2	96.4	95.3	17.5	22.22	19.86	18.49	18.73
72	68	68	68	65.4	96.3	92.8	96.8	95.8	17.6	23.21	20.84	21.46	21.29
74	70	73	72	64.6	96.5	91.2	97.2	96.1	17.6	23.93	21.58	23.5	23.01
75	71	76	74	72.4	96.6	91.0	97.4	96.2	18.3	24.63	22.84	25.06	23.67
75	70	73	71	66.0	96.7	90.9	97.2	95.5	17.5	23.08	19.3	20.86	19.79
74	66	68	67	66.5	97.0	92.0	96.5	94.8	16.9	23.42	19.24	19.05	19.63
74	66	64	66	67.7	95.6	92.2	80.5	77.8	16.8	22.97	19.26	17.2	18.72
73	67	61	64	67.1	92.9	92.8	75.2	75.8	17.1	22.88	19.63	16.33	18.51
71	67	61	65	65.8	75.8	93.1	78.6	76.9	17.3	22.71	19.92	16.53	18.83
69	68	60	64	74.1	64.4	89.4	75.1	72.3	15.7	22.33	20.01	16.52	18.82
68	67	60	63	76.8	66.0	77.5	77.3	71.8	14.6	21.49	20.16	15.72	18.3
68	66	59	63	79.3	65.0	73.1	79.2	72.1	13.7	21.29	19.75	15.34	17.68
67	66	60	64	80.0	65.7	68.6	81.8	74.9	13.5	20.84	19.6	15.32	17.73
68	66	62	65	80.7	73.0	70.3	83.4	80.5	13.5	20.7	19.42	16.57	18.33
67	65	63	65	80.9	63.4	73.4	78.1	81.1	13.5	20.72	19.33	17.36	18.7
66	65	64	65	81.2	65.5	71.7	71.9	78.2	13.5	20.12	19.18	18.07	18.89
65	65	65	65	81.2	65.3	68.6	68.9	74.8	13.5	19.4	19.38	19	18.97
65	65	66	65	81.7	68.2	68.9	68.0	74.0	13.4	18.97	19.24	19.52	18.99
65	65	66	65	81.7	68.7	72.3	68.5	71.8	13.5	18.82	19.24	20.02	19.08
65	65	65	65	80.8	72.9	68.6	62.1	68.8	13.3	19.1	19.32	19.09	18.93
65	65	62	64	81.7	68.4	65.3	65.6	68.5	13.0	19.47	19.32	17.2	18.52
65	64	61	65	81.4	67.4	65.5	68.2	67.7	13.0	19.31	18.75	16.34	19.46
66	64	60	66	82.3	71.0	66.8	72.2	63.6	13.1	19.43	18.42	15.93	19.69
66	64	60	64	81.9	68.2	68.2	73.8	67.0	13.0	19.81	18.73	15.58	18.46
66	63	59	63	82.4	63.2	67.3	74.6	66.9	12.6	20.24	17.8	15.06	17.93
65	62	59	63	84.8	64.2	67.3	75.2	69.8	12.3	19.53	17.49	14.95	17.7
65	62	59	64	85.4	68.8	70.9	77.4	69.6	12.3	18.86	17.18	14.88	18.37
65	62	60	64	84.4	72.3	73.1	77.3	73.8	12.5	18.93	17.37	15.42	18.61
66	62	60	64	83.7	74.4	72.3	76.2	71.7	12.9	19.62	17.29	15.72	18.48
67	62	60	64	78.7	71.1	71.6	74.7	69.6	14.3	20.48	17.13	15.47	18.34
66	62	59	63	77.7	65.0	70.8	74.2	67.8	13.5	20.1	17.29	15.21	18.13
66	62	59	63	78.7	65.5	69.4	73.7	66.0	13.2	19.57	17.24	15.07	18.08
64	62	59	62	79.4	66.4	68.6	73.5	69.2	12.8	18.79	17.04	14.94	17.37
63	61	58	61	80.4	66.2	68.9	75.7	69.7	12.3	18.19	16.67	14.17	16.31
63	61	57	60	80.5	67.3	69.8	78.4	71.5	12.2	17.69	16.15	13.67	15.88
63	60	57	60	80.6	68.3	70.5	79.3	71.1	12.3	17.48	15.93	13.62	16.04
63	61	57	61	77.4	70.3	70.3	77.7	69.9	12.8	17.61	16.31	13.97	16.35
63	61	58	61	75.1	67.5	69.7	76.4	69.9	13.9	17.91	16.28	14.4	16.76
63	61	59	62	74.8	69.3	69.1	74.1	70.4	13.9	18.09	16.72	14.91	16.83
64	62	60	62	73.7	65.8	68.6	74.7	69.2	13.9	18.33	16.93	15.1	16.84
64	62	61	62	72.5	64.2	66.4	69.7	67.6	14.0	18.35	17.02	16.51	17.42

Heat map 3:

Comparison of temperatures recorded in January and July

21.1.17					25.1.17					20.7.16					27.7.16				
Amb.T	BF	BM	TM	TF	Amb.T	BF	BM	TM	TF	Amb.T	BF	BM	TM	TF	Amb.T	BF	BM	TM	TF
14.8	15.0	15.2	15.7	15.6	23.8	22.8	22.5	22.3	22.2	8.6	9.3	9.2	8.9	8.3	9.5	8.9	9.7	9.8	9.9
14.8	14.9	15.2	15.6	15.5	25.2	22.7	21.9	22.3	22.4	10.8	9.1	9.1	8.7	8.3	8.9	9.3	9.5	9.7	9.9
14.8	14.9	15.2	15.5	15.5	26.1	22.6	21.5	22.1	22.3	11.8	8.1	8.1	7.6	7.0	8.2	7.9	8.3	8.3	8.5
14.8	14.9	15.2	15.5	15.4	26.5	23.5	22.8	22.1	22.2	10.7	8.5	7.5	7.6	6.7	7.3	10.1	9.1	9.0	8.4
15.4	15.2	15.2	15.4	15.4	26.6	24.1	22.9	22.1	22.3	9.6	10.7	9.5	9.6	8.4	6.5	13.0	11.5	11.2	9.5
15.8	14.6	14.3	14.5	14.7	26.9	25.1	23.6	22.2	22.6	8.9	13.1	12.1	11.2	9.5	5.9	15.9	13.6	12.9	11.2
17.0	15.6	14.8	13.8	14.1	26.6	25.8	23.6	22.8	23.3	8.4	15.3	14.4	12.5	10.2	5.4	18.6	15.0	15.4	12.3
17.2	17.1	16.0	13.7	14.0	26.3	26.4	24.3	23.8	24.2	7.8	17.8	15.9	13.7	10.4	5.0	20.3	16.3	17.1	12.5
17.3	18.9	17.6	13.9	14.3	26.2	27.5	24.9	24.7	25.1	7.4	18.4	16.5	15.1	10.5	4.5	21.6	16.5	17.9	13.4
17.4	20.7	18.3	14.8	15.4	26.2	27.3	24.5	25.4	25.9	7.0	19.4	16.5	16.1	11.9	4.2	22.4	15.6	19.1	14.9
17.5	22.0	19.8	17.1	17.7	26.1	26.9	24.5	25.9	26.7	7.0	20.9	16.6	16.8	13.0	4.0	22.8	14.8	19.9	15.7
17.6	22.6	20.4	20.1	19.9	26.1	27.3	25.4	26.4	27.3	6.9	22.0	17.0	17.5	13.0	3.8	22.5	14.0	20.8	16.9
17.6	23.6	21.5	22.7	22.4	26.3	27.5	25.0	26.6	27.9	6.9	22.6	17.7	18.1	12.8	3.8	22.0	14.2	20.8	17.3
18.2	24.2	22.1	24.5	23.4	27.4	27.7	25.5	24.6	28.3	7.9	22.8	18.1	18.9	12.8	6.5	22.3	14.6	21.1	17.8
17.9	24.3	21.4	22.9	21.6	26.7	27.9	25.4	23.8	27.5	6.7	23.4	16.8	18.4	12.2	7.0	22.7	14.2	20.6	17.6
16.7	23.3	19.3	20.4	19.6	25.3	27.7	25.6	24.4	27.2	7.8	22.3	15.5	18.2	11.7	7.1	22.8	14.0	19.5	16.1
17.0	23.6	19.3	18.2	19.2	23.7	27.4	25.1	24.3	27.1	7.4	22.3	14.4	18.0	12.6	7.8	22.7	14.4	18.3	15.5
16.9	23.0	19.4	16.7	18.5	22.8	26.9	25.6	24.2	26.7	7.2	21.7	13.6	17.1	12.6	8.7	22.7	14.9	17.6	14.6
17.3	22.7	19.9	16.5	18.8	22.1	26.8	25.4	24.8	26.6	6.5	21.0	12.9	16.7	12.1	6.4	21.7	15.0	16.3	13.7
14.5	21.8	20.2	16.0	18.5	22.4	26.6	25.0	25.0	26.2	4.2	19.8	12.6	15.6	11.1	5.3	20.8	14.9	15.5	13.5
14.1	21.3	20.0	15.5	18.0	22.5	26.6	25.0	25.4	25.8	3.6	18.7	13.1	15.4	10.6	5.4	21.0	14.7	15.5	14.0
13.4	21.1	19.7	15.2	17.6	25.4	26.6	24.7	24.8	25.3	3.6	18.5	13.0	15.5	11.0	5.8	21.5	14.9	16.6	14.8
13.5	20.7	19.5	15.8	18.2	24.4	26.5	25.2	25.1	25.1	3.3	17.6	12.3	15.7	11.8	6.0	21.6	15.3	18.1	15.5
13.5	20.7	19.5	17.0	18.6	22.8	26.9	25.7	25.6	25.8	3.3	16.4	11.5	15.4	12.7	6.0	21.4	15.2	18.8	15.9
13.5	20.5	19.2	17.8	18.8	22.4	26.9	26.3	25.5	25.9	3.8	15.7	10.7	15.3	13.5	5.9	20.6	15.0	18.4	16.1
13.5	19.9	19.2	18.4	19.0	22.1	27.1	26.4	25.7	26.2	4.4	15.7	10.4	15.5	14.1	5.9	19.5	14.8	18.2	16.3
13.5	19.4	19.4	19.0	19.0	22.6	27.3	26.2	25.7	26.5	4.6	15.9	10.6	16.2	14.9	6.4	19.1	14.9	18.2	16.5
13.4	19.0	19.2	19.5	19.0	22.9	27.2	26.0	25.8	26.5	4.9	16.4	10.9	17.0	16.0	6.8	19.2	14.8	18.6	17.1
13.5	18.8	19.2	20.0	19.1	23.7	27.2	26.3	26.2	26.6	4.9	16.6	11.3	17.4	17.3	7.0	19.5	15.8	19.1	18.1
13.3	19.1	19.3	19.1	18.9	24.2	27.4	26.5	26.8	27.0	5.0	16.3	11.8	17.4	18.4	7.2	19.9	16.2	19.6	19.5
13.0	19.5	19.3	17.2	18.5	25.0	27.7	26.6	27.5	27.6	5.1	15.8	12.0	17.4	19.7	7.3	20.4	16.2	20.3	21.2
13.0	19.3	18.8	16.3	19.5	25.9	28.1	26.9	28.0	28.0	5.1	15.3	12.2	17.6	21.0	7.7	21.0	16.5	20.6	21.8
13.1	19.4	18.4	15.9	19.7	26.6	28.4	27.1	28.4	28.4	5.2	15.1	12.5	17.7	22.0	8.5	20.7	16.2	19.7	21.7
13.0	19.8	18.7	15.6	18.5	27.3	28.7	27.3	28.8	28.8	5.9	15.5	13.1	17.6	21.4	9.6	19.9	16.2	18.7	20.1
12.6	20.2	17.8	15.1	17.9	27.6	29.0	27.6	29.2	29.1	5.9	15.9	13.0	16.8	18.4	9.4	19.0	16.0	17.7	19.4
12.3	19.5	17.5	15.0	17.7	28.0	29.2	27.8	29.5	29.5	6.0	16.3	12.5	15.9	15.6	9.7	18.4	15.8	17.0	19.1
12.3	18.9	17.2	14.9	18.4	27.4	28.9	27.6	28.7	29.3	7.1	16.7	12.3	15.5	14.7	10.2	18.2	15.7	17.2	17.8
12.5	18.9	17.4	15.4	18.6	25.7	28.4	27.0	27.3	28.6	7.9	16.9	12.4	15.3	14.2	10.4	18.0	15.7	17.0	16.6
12.9	19.6	17.3	15.7	18.5	24.1	27.8	26.3	26.7	27.7	8.3	17.2	12.5	15.6	13.8	10.0	18.4	15.9	16.7	15.7
14.3	20.5	17.1	15.5	18.3	23.5	27.4	26.3	26.5	27.2	8.3	17.5	12.6	15.5	13.4	9.9	17.9	16.0	16.9	15.3
13.5	20.1	17.3	15.2	18.1	23.6	27.5	26.5	26.5	27.2	8.3	17.0	13.1	15.8	13.5	10.0	17.7	15.8	16.7	14.9
13.2	19.6	17.2	15.1	18.1	23.5	26.9	25.7	24.9	26.3	8.8	16.7	13.8	16.9	13.5	9.8	17.1	15.6	16.4	14.4
12.8	18.8	17.0	14.9	17.4	23.1	26.2	25.4	24.0	24.9	9.2	16.6	14.0	17.0	13.9	10.2	17.0	15.4	16.3	14.1
12.3	18.2	16.7	14.2	16.3	21.9	25.1	24.0	22.2	23.4	9.1	17.1	14.2	16.5	13.7	10.5	16.9	15.1	16.1	14.0
12.2	17.7	16.2	13.7	15.9	19.9	23.5	22.9	21.0	21.9	9.5	17.3	14.9	16.5	13.3	10.4	17.0	14.8	15.8	13.9
12.3	17.5	15.9	13.6	16.0	18.3	23.1	22.3	20.0	21.1	10.7	17.5	15.1	16.6	14.0	10.4	17.8	14.7	16.1	13.9
12.8	17.6	16.3	14.0	16.4	17.9	22.7	21.8	19.5	20.4	11.5	17.2	15.1	16.7	14.4	10.2	19.5	14.8	17.0	14.1
13.9	17.9	16.3	14.4	16.8	18.1	22.1	21.9	19.1	19.9	11.8	18.4	15.2	16.4	14.3	10.2	19.6	14.9	17.2	14.0
13.9	18.1	16.7	14.9	16.8	18.4	21.8	21.4	19.3	19.6	12.1	20.1	15.4	16.1	14.1	9.8	19.0	15.1	16.7	13.9
13.9	18.2	16.9	15.9	17.2	17.3	21.5	20.6	18.7	19.3	11.3	21.1	15.3	16.2	14.1	8.5	18.9	15.2	16.0	13.5
14.0	18.3	17.2	16.5	17.5	16.4	20.5	19.5	17.8	18.3	10.7	21.4	15.3	16.8	14.3	8.1	18.1	15.0	15.8	13.4
14.3	18.3	17.0	16.4	17.5	16.2	19.7	19.1	17.2	17.7	9.9	21.3	15.1	16.5	14.2	8.4	17.7	15.3	16.2	13.2
16.6	18.8	17.8	17.4	17.9	16.7	19.1	18.9	17.0	17.6	9.8	20.8	15.2	17.4	14.1	8.6	17.5	15.2	17.2	13.3
17.6	19.4	17.8	18.7	18.3	16.6	19.1	18.5	17.0	17.7	10.0	20.7	15.8	17.4	14.1	9.3	17.5	15.2	17.8	14.0
18.6	19.7	17.9	19.6	18.9	17.2	19.4	18.2	17.2	17.8	10.2	21.3	16.1	17.1	14.2	10.7	17.5	15.4	18.7	14.5
19.2	20.0	18.0	20.3	19.9	17.6	19.5	18.4	17.8	17.7	10.7	22.3	16.3	17.5	14.2	12.0	17.3	15.7	20.6	14.7
19.4	20.6	18.1	20.4	20.2	17.2	20.2	19.0	18.2	18.6	12.1	22.7	16.8	17.7	14.6	12.9	17.3	15.9	21.2	15.3

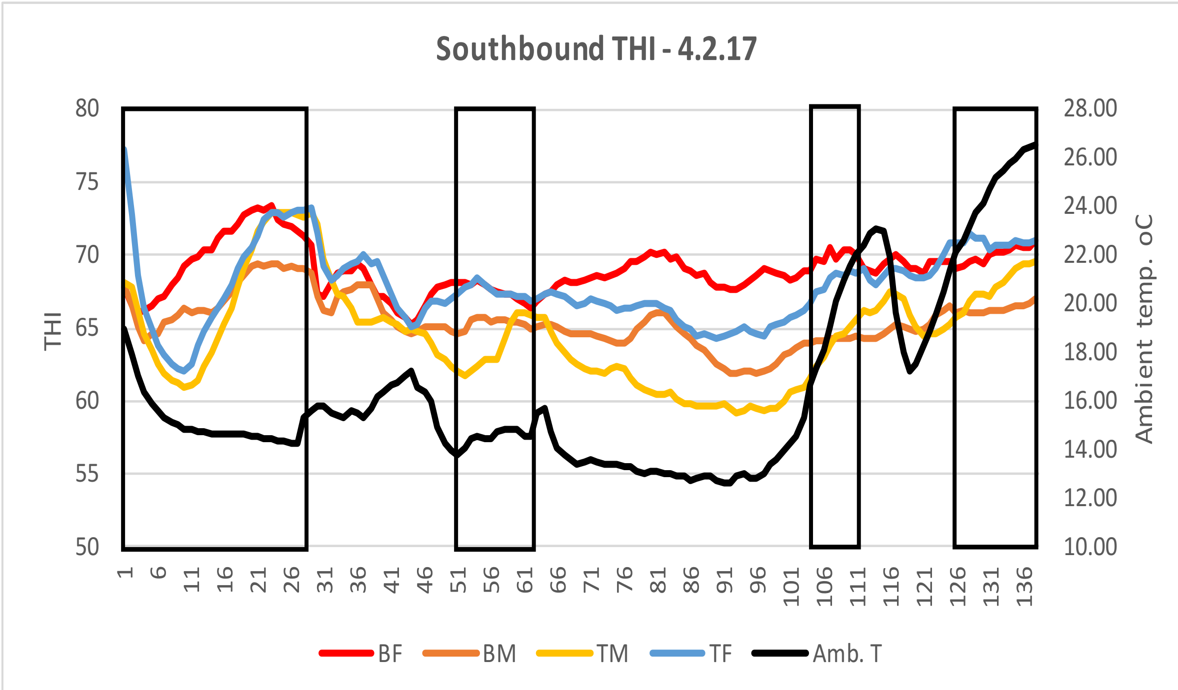
Vehicle Stationary Periods

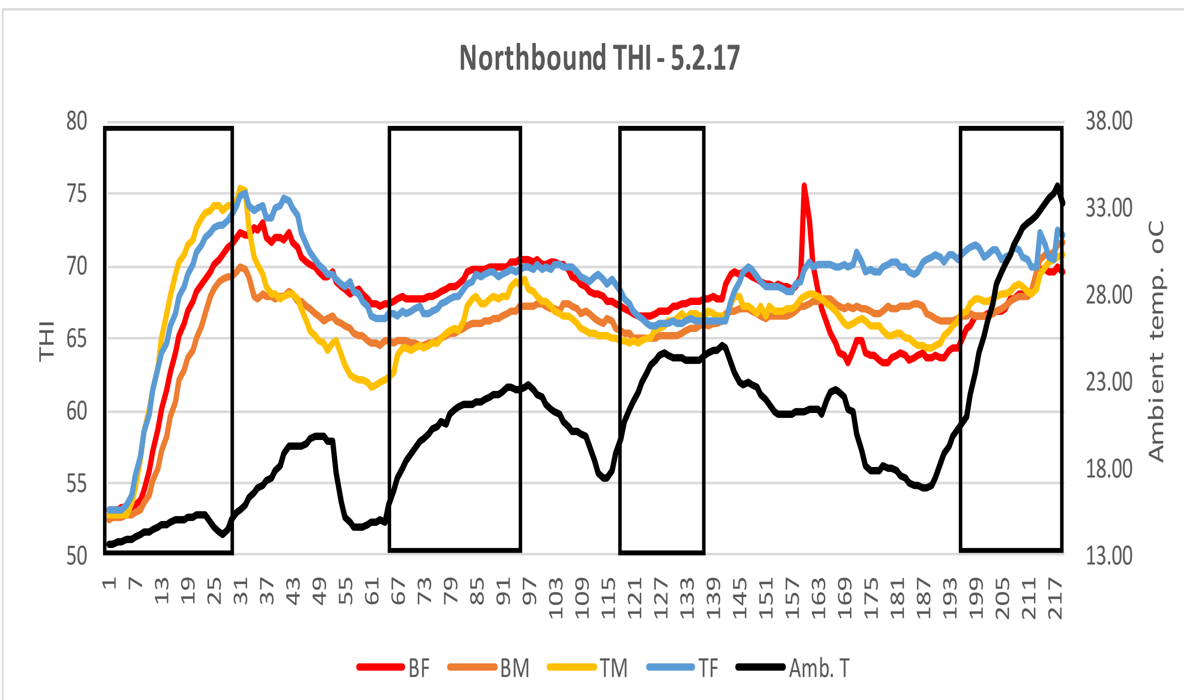
Amb. T = Ambient Temperature   BF = Bottom Front   BM = Bottom Middle   TM = Top Middle   TF = Top Front

Heat map 4: Comparison of THI ranges during two weeks in summer and winter

21.1.17					25.1.17					20.7.16					27.7.16				
Amb. T	BF	BM	TM	TF	Amb. T	BF	BM	TM	TF	Amb. T	BF	BM	TM	TF	Amb. T	BF	BM	TM	TF
14.8	59	59	60	60	23.8	69	69	69	68	8.6	50	50	50	49	9.5	50	51	51	52
14.8	59	59	60	60	25.2	69	68	68	68	10.8	50	50	50	49	8.9	51	51	51	52
14.8	59	59	60	60	26.1	71	68	68	69	11.8	49	49	48	47	8.2	48	49	48	49
14.8	59	59	59	59	26.5	73	71	68	69	10.7	48	46	46	45	7.3	50	49	49	48
15.4	59	59	59	60	26.6	73	70	68	69	9.6	51	49	49	47	6.5	56	53	52	49
15.8	58	58	58	58	26.9	76	72	69	70	8.9	56	54	52	49	5.9	61	57	55	52
17.0	60	59	57	57	26.6	73	72	70	70	8.4	60	58	55	51	5.4	65	59	60	54
17.2	63	61	57	57	26.3	76	73	72	73	7.8	64	61	57	51	5.0	68	61	63	55
17.3	66	64	57	58	26.2	81	74	74	73	7.4	65	62	59	51	4.5	70	62	64	56
17.7	64	61	56	57	26.2	79	72	75	74	7	67	62	61	54	4.2	72	60	66	59
17.5	71	67	63	64	26.1	78	73	75	75	7	69	62	62	55	4.0	73	59	68	60
17.6	72	68	68	68	26.1	76	74	75	76	6.9	71	63	63	55	3.8	71	57	69	62
17.6	74	70	73	72	26.3	76	73	75	77	6.9	72	64	64	55	3.8	70	58	69	63
18.2	75	71	76	74	27.4	77	72	72	78	7.9	73	64	66	55	6.5	70	58	70	64
17.9	75	70	73	71	26.7	76	72	69	75	6.7	74	62	65	54	7.0	70	58	69	64
16.7	74	66	68	67	25.3	75	72	70	74	7.8	70	60	65	53	7.1	70	57	66	61
17.0	74	66	64	66	23.7	75	72	71	74	7.4	69	58	64	55	7.8	70	58	63	60
16.9	73	67	61	64	22.8	74	73	71	74	7.2	68	57	63	55	8.7	70	59	62	58
17.3	71	67	61	65	22.1	74	74	72	74	6.5	67	56	61	54	6.4	67	59	61	57
14.5	69	68	60	64	22.4	74	72	72	74	4.2	65	55	59	53	5.3	66	59	59	57
14.1	68	67	60	63	22.5	74	72	72	73	3.6	64	56	59	52	5.4	67	58	60	57
13.4	68	66	59	63	25.4	73	71	72	72	3.6	64	56	60	52	5.8	69	59	62	59
13.5	67	66	60	64	24.4	74	73	72	72	3.3	62	55	60	54	6.0	69	60	64	60
13.5	68	66	62	65	22.8	75	73	72	74	3.3	61	54	59	55	6.0	67	59	64	60
13.5	67	65	63	65	22.4	74	74	72	73	3.8	60	52	59	56	5.9	66	59	63	61
13.5	66	65	64	65	22.1	77	74	72	74	4.4	60	52	60	57	5.9	65	59	63	61
13.1	66	64	64	65	22.6	75	73	72	73	4.6	60	52	61	59	6.4	65	59	64	61
13.4	65	65	66	65	22.9	74	72	72	73	4.9	61	52	62	61	6.8	65	59	64	62
13.5	65	65	66	65	23.7	75	76	73	74	4.9	61	53	62	63	7.0	65	60	65	64
13.3	65	65	65	65	24.2	75	76	74	74	5	60	54	62	64	7.2	66	61	66	66
13.0	65	65	62	64	25.0	76	75	75	74	5.1	60	54	62	65	7.3	67	61	68	69
13.0	65	64	61	65	25.9	77	75	75	74	5.1	59	55	62	67	7.7	67	62	66	68
13.1	66	64	60	66	26.6	76	75	75	75	5.2	59	55	62	68	8.5	66	61	65	67
13.0	66	64	60	64	27.3	76	75	75	75	5.9	59	56	62	66	9.6	65	61	63	65
12.6	66	63	59	63	27.6	76	75	76	75	5.9	60	56	61	63	9.4	64	60	62	65
12.3	65	62	59	63	28.0	77	75	75	76	6	61	55	60	59	9.7	63	60	61	64
12.3	65	62	59	64	27.4	75	73	74	75	9.2	61	57	61	57	10.2	63	60	62	62
12.5	65	62	60	64	25.7	74	73	72	74	9.1	61	58	61	57	10.4	63	60	61	61
12.9	66	62	60	64	24.1	73	72	72	73	9.5	62	59	61	56	10.0	63	60	61	60
14.3	67	62	60	64	23.5	72	71	70	71	10.7	62	59	61	57	9.9	63	60	61	59
13.5	66	62	59	63	23.6	73	72	73	72	11.5	62	59	61	58	10.0	62	60	61	59
13.2	66	62	59	63	23.5	74	72	71	73	11.8	64	59	61	58	9.8	62	60	61	58
12.8	64	62	59	62	23.1	73	72	71	72	12.1	66	59	60	58	10.2	62	59	60	58
12.3	63	61	58	61	21.9	72	71	68	70	11.3	67	59	60	58	10.5	61	59	60	57
12.2	63	61	57	60	19.9	70	70	67	68	10.7	67	59	61	58	10.4	61	59	60	57
12.3	63	60	57	60	18.3	70	69	66	67	9.9	67	59	61	58	10.4	63	58	60	57
12.8	63	61	57	61	17.9	70	68	65	66	9.8	66	59	62	58	10.2	66	59	62	58
13.9	63	61	58	61	18.1	69	68	65	66	10	66	60	62	58	10.2	65	59	62	57
13.9	63	61	59	62	18.4	68	68	65	65	10.2	68	60	61	58	9.8	64	59	61	57
13.9	64	62	59	62	18.1	68	67	65	65	10.7	70	61	62	58	8.5	64	59	60	57
13.9	64	62	60	62	17.3	68	66	64	65	12.1	68	62	63	58	8.1	63	59	60	56
14.0	64	62	61	62	16.4	67	65	63	64	12.6	67	62	64	59	8.4	62	59	60	56
14.3	64	62	61	63	16.2	65	65	62	63	12.8	67	62	66	61	8.6	62	59	62	56
16.6	65	63	63	63	16.7	65	65	62	63	13	67	63	66	64	9.3	62	59	62	57
17.6	65	63	65	64	16.6	65	64	62	63	13.1	67	63	67	66	10.7	62	59	64	58
18.6	66	63	66	65	17.2	65	64	62	63	13.2	66	63	66	67	12.0	62	60	67	58
19.2	67	63	67	67	17.6	66	64	63	63	13.3	65	62	65	67	12.9	62	60	67	59
19.4	67	63	66	66	17.2	66	65	64	64	13.5	65	62	65	67	13.2	62	60	67	60

Differences in THI levels recorded between the southbound and northbound journeys:





Graphs 10 & 11: THI levels during southbound and northbound journeys during summer

The impact of changing the stock density in the bottom front pen

Data from five journeys, each with similar ambient temperature ranges, were examined to look at the effect that having no pigs, ten pigs or 14 pigs in the bottom front and middle pens (on the lower deck), had on the temperature and humidities recorded in those pens. The data was collected from journeys made during different seasons with the selection criterion being focused on the ambient temperature range.

Table 6: The temperature effect of changing stocking density in the bottom front pen during loading on five comparable winter journeys

Pen empty			**10 pigs in pen**			**14 pigs in pen**		
Ambient	BF	Diff.	Ambient	BF	Diff.	Ambient	BF	Diff.
9.00	7.67	-1.33	6.01	9.91	+3.90	14.01	19.29	+5.28
15.34	14.04	-1.30	10.28	14.37	+4.09	11.03	15.06	+4.03
14.09	9.15	-4.94	6.67	11.51	+4.84	8.37	16.04	+7.67
3.80	3.72	-0.08	6.55	9.72	+3.17	11.03	15.06	+4.03
6.93	5.79	-1.14	7.00	9.96	+2.96	11.81	16.85	+5.04
	Average	-1.76 ± 0.83		Average	+3.79 ± 0.34		Average	+5.21 ± 0.67

Table 7: The effect of the stocking density on temperature, THI and humidity during the loading of the bottom deck

Average temperature range during loading

° C	Amb	BF	BM
MT	3.4	-2	-1.4
10/pen	2.0	7.4	7.4
14/pen	4.8	9.0	7.0

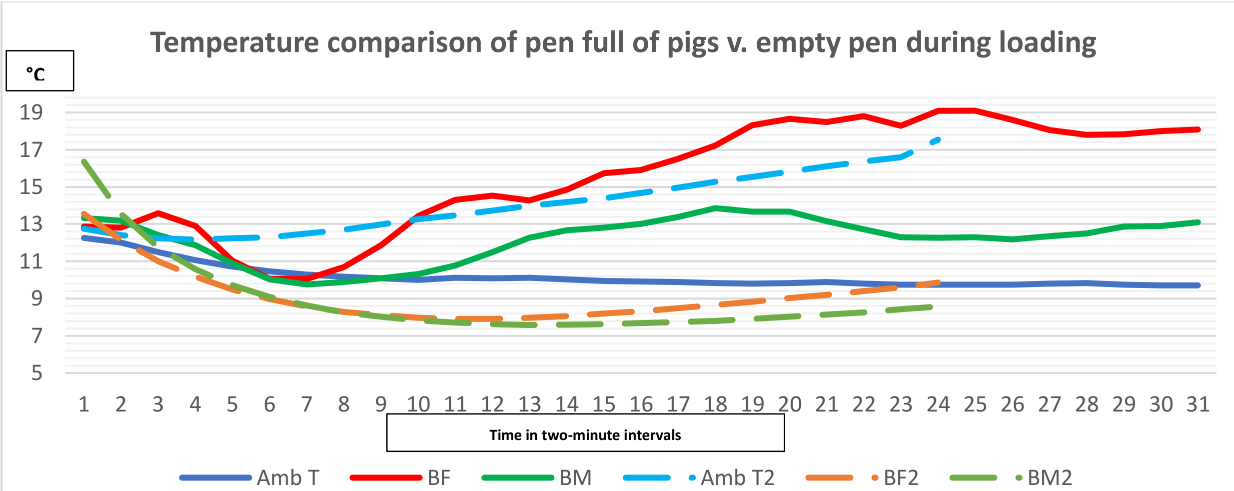
Average THI range during loading

	Amb	BF	BM
MT	4.8	8.2	6.6
10/pen	3.8	12.6	11.4
14/pen	7	14	14

Average humidity range during loading

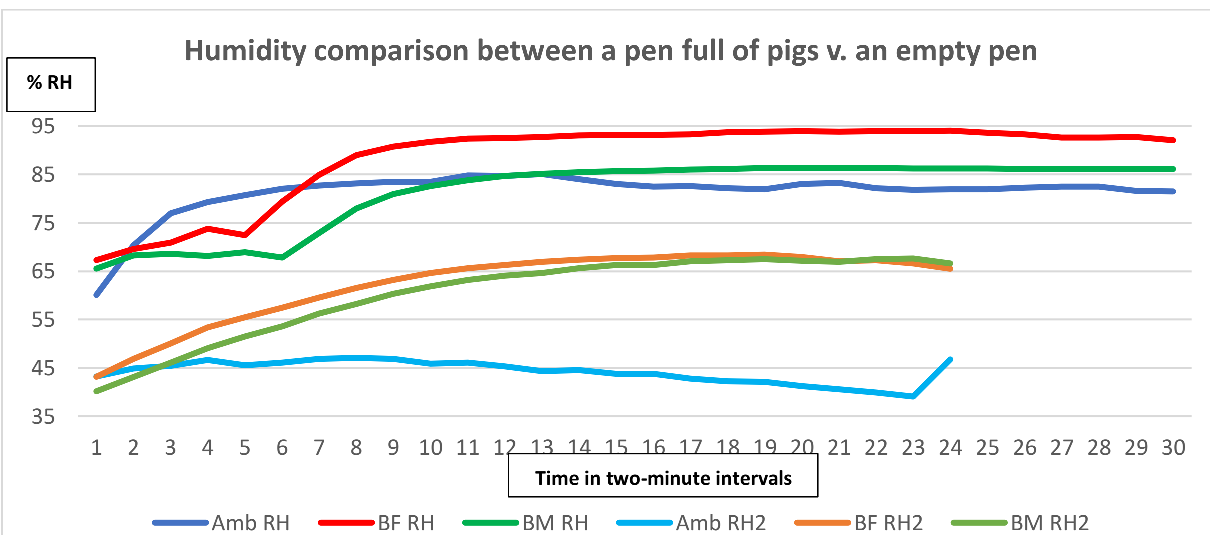
% RH	Amb	BF	BM
MT	9.8	16.6	17.2
10/pen	10.2	22.2	19.2
14/pen	20.0	25.0	29.0

Where: Ambient = ambient MT = pen empty BF = the bottom front pen BM. = the bottom middle pen



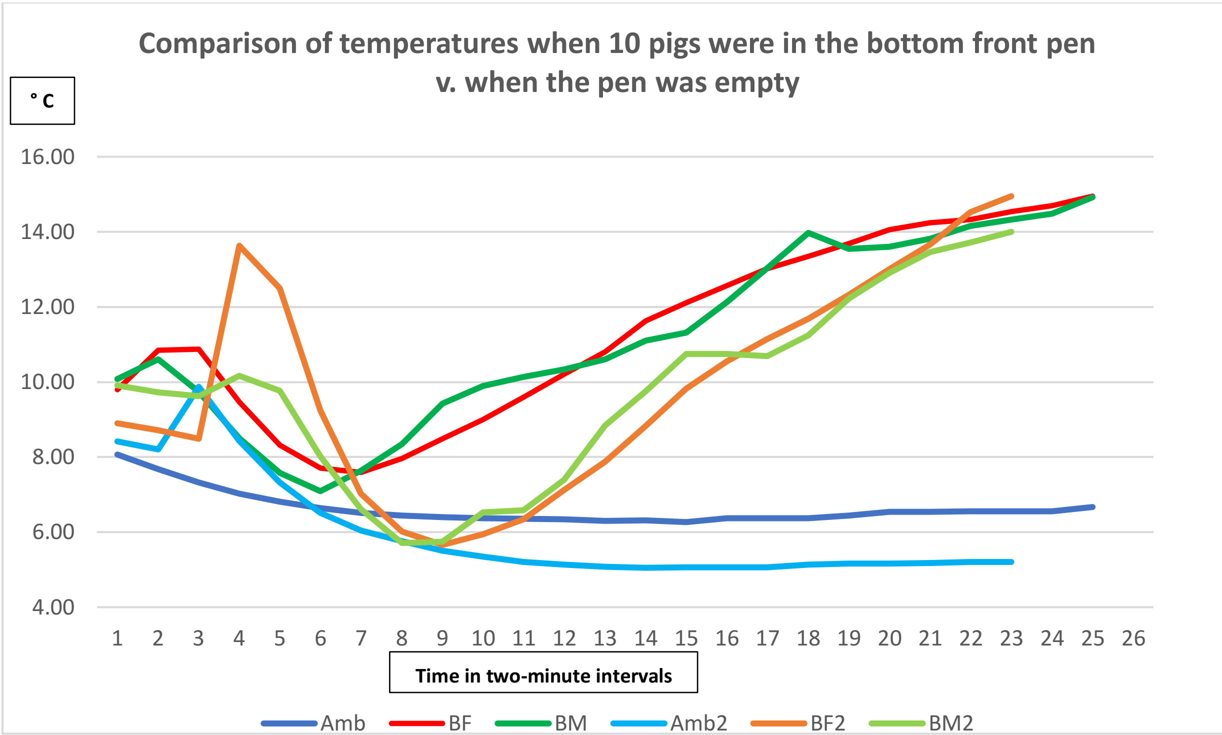
Where: Amb T = Ambient temperature when 14 pigs were in the bottom front pen Amb T2 = Ambient temperature when the bottom front pen was empty BF = The bottom front pen when 14 pigs were in the pen BF2 = The bottom front pen when empty BM = The bottom middle pen when 14 pigs were in the pen BM2 = The bottom middle pen when empty

Graph 12: Comparison of the effect on temperature between a pen with 14 pigs and an empty pen on the bottom deck of a fully loaded stock-crate



Where: Amb RH = Ambient relative humidity when 14 pigs were in the bottom front pen Amb RH2 = Ambient relative humidity when the bottom front pen was empty BF RH = The bottom front pen when 14 pigs were in the pen BF2 RH = The bottom front pen when empty BM RH = The bottom middle pen when 14 pigs were in the pen BM2 RH = The bottom middle pen when empty

Graph 13: Comparison of the effect on humidity between a pen with 14 pigs and an empty pen on the bottom deck of a fully loaded stock-crate

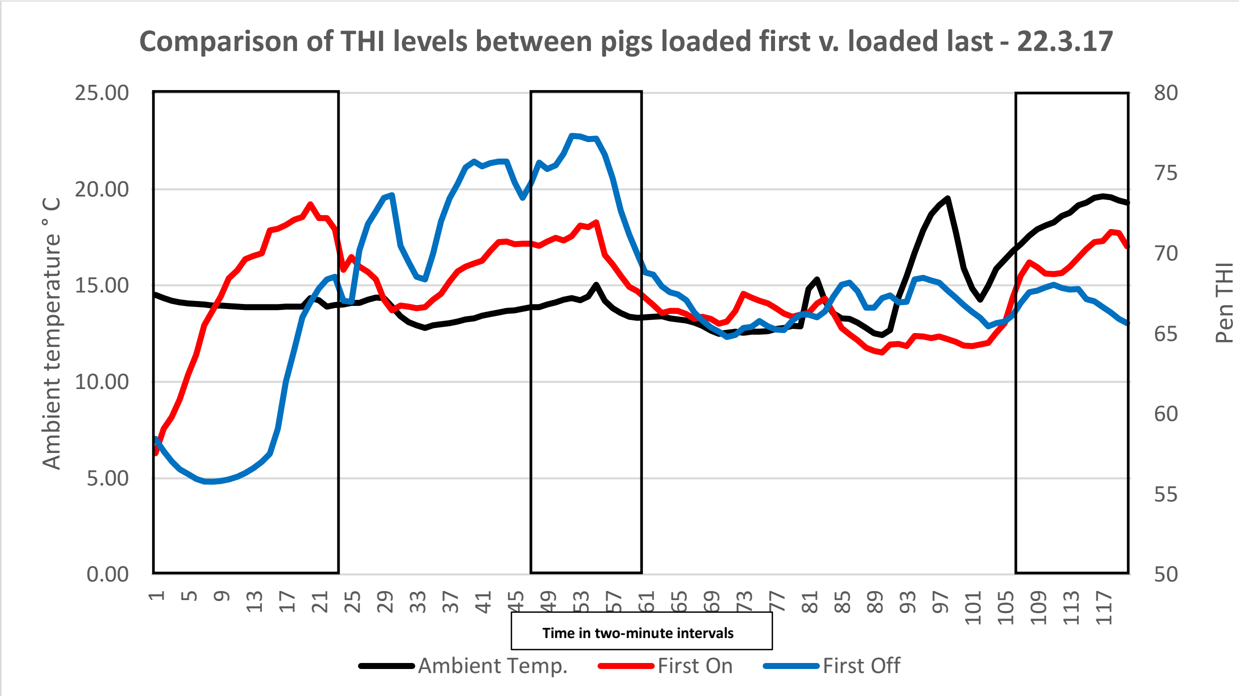


Graph 14: Comparison of the effect on temperature between a pen with 10 pigs and an empty pen

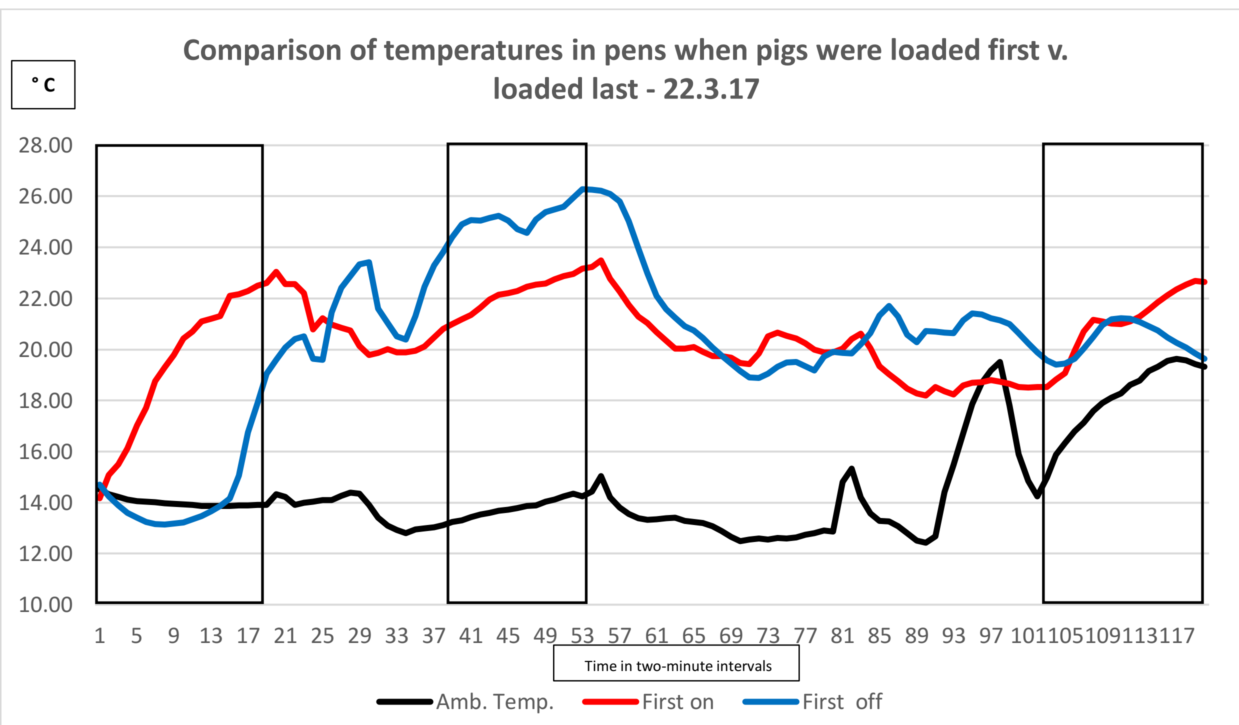
Contrasting the environments in the bottom front pen and the top rear pen of the trailer

Because pigs, during the northbound journeys, were not penned in but had freedom to roam throughout the bottom deck, only the southbound journeys were monitored for this section of the study. During the southbound journeys, pigs were only penned on the bottom two decks in the truck and trailer stock-crates. The upper two decks of the stock-crates were left empty with the floor above the upper level of pigs being left in place as a ceiling.

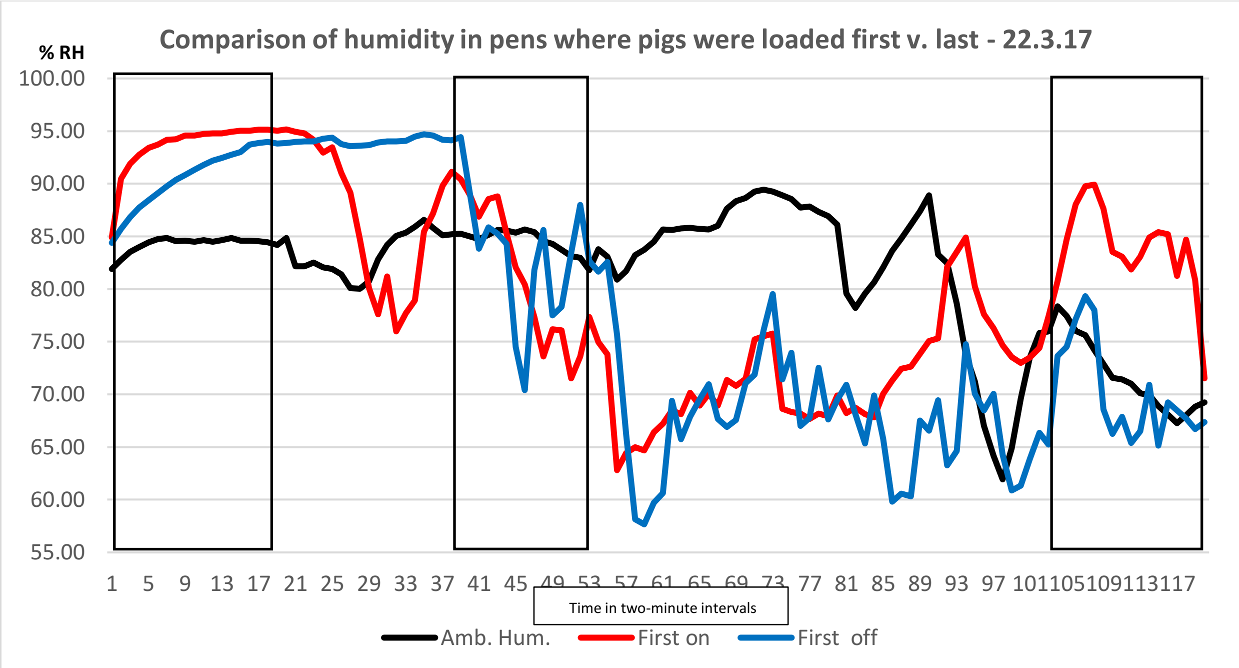
The first pigs to be loaded were penned in the bottom front pen and the last pigs to be loaded were penned in the rear-most pen on the upper level of the trailer. A logger was installed on the front wall of the rear-most pen that held the last pigs to be loaded to record the environment within that pen.



Graph 15: **THI levels in pens where pigs were loaded first versus last**



Graph 16: **Temperature levels in pens where pigs were loaded first versus last**



Graph 17: Humidity levels in pens where pigs were loaded first versus last

The level of the THI values recorded during the study

Records for 100 days, evenly spread between southbound and northbound journeys and month of the year, were examined over a three-year period. THI levels were based on the internationally accepted (Hahn *et al*., 2009) THI values for pigs where Severe cold-stress = THI up to 40; Cold-stress = THI up to 50; Comfort zone = THI 60 to 70; Heat-stress = THI greater than 70 and potentially lethal heat-stress = THI greater than 80.

Table 8: Percentage of days when heat-stress was recorded

Days within the comfort zone	31%	
Days of heat-stress	69%	includes 20 days of critical heat-stress
Days of cold-stress	21%	includes 2 days of severe cold-stress
Days when heat-stress only occurred in the bottom deck	6%	
Days when heat-stress only occurred in the top deck	5%	

Table 9: The effect of season on heat-stress levels during 100 journeys

Southbound

	No. days	Loading %	Moving %	Stationary period %	Moving %
Dec to Feb	17	82	47	53	35
Mar to May	12	50	17	58	8
Jun to Aug	7	43	0	0	0
Sep to Nov	10	10	10	30	10
Total	46				

Northbound

	No. days	Loading %	Moving %	Stationary period %	Moving %	Stationary period %	Moving %
Dec to Feb	16	75	31	56	44	31	50
Mar to May	13	69	15	46	15	23	62
Jun to Aug	10	20	0	20	0	10	10
Sep to Nov	15	47	27	27	20	27	33
Total	54						

Where: % = the percentage of the number of days when THI levels were greater than 71

A separate set of data looked at 50 journeys, *spread evenly between seasons*, the location within the stock-crates, where THI levels greater than 71 were recorded, was calculated.

Table 10: Location where THI greater than 71 occurred

Location when THI greater than 71 occurred

All locations below THI 72	42%
Both top and bottom decks affected equally	62%
72+ only occurred when the vehicle was stationary	24%
72+ only occurred when the vehicle was moving	17%

When moving - more times on the top deck than the bottom deck (76% v. 65%)
When stationary - as many times on the top deck as the bottom deck

DISCUSSION

The findings in the pre-study report

The abattoir staff were instructed to only record DOA and DIY events from vehicles that serviced commercial piggeries. Data was not collected from the small number of suppliers who brought their pigs to the abattoir on a range of small trucks or trailers. As was normal practice, pigs from the small piggeries were processed after a minimum of lairage time so that no DIY pigs resulted from their supply; had any pigs arrived dead they would have been taken back to the farm of origin for disposal.

The results of the 2008-2011 study were spread between all months of the year and showed that 35% of the dead pigs were found in the bottom front pen, 62% in the pens on the bottom deck of the truck and 24% on the bottom deck of the trailer; a total of 86% being in pens on either the bottom deck of the truck or trailer. The two pigs that were found dead on the top deck of the trailer occurred during the summer when pigs were being transported on the third deck.

These findings indicate that conditions on the bottom deck of both the truck and trailer were stressful and that less stressful conditions occurred on the top decks. This suggests that stocking densities and/or ventilation of the lower decks may be inappropriate in New Zealand-designed stock transporters. All of the drivers spoken to indicated that they adjusted their stocking densities according to ambient temperatures by adding one or two more pigs per pen during the winter months or reducing the number of pigs per pen during the summer months.

Drivers increase stocking densities in very cold weather but it would appear that such a practice might contribute to the DOA/DIY rate that has been recorded during the winter months in New Zealand. Table 4 shows that the temperature difference between ambient and the bottom front pen was 4° C in Summer, 4.7° C in Autumn, 6.8° C in Winter and 6.1° C in Spring indicating that using ambient temperatures to assess conditions within a stock-crate would be unreliable.

Increasing the stocking density at the beginning of a journey would lead to increased heat being produced within the pens later in the day when ambient temperatures increase. Since midday winter temperatures can be high (Table 2), the result of increasing the stocking density at the beginning of the journey could lead to significant heat-stress conditions when the vehicle was stationary later in the day; a factor that could explain the 'paradoxical heat-stress' and DOA pigs recorded during the winter months.

The impact of the weather and climate recorded during the study

<u>*The climate in Canterbury*</u>: The climate in Canterbury differs from the regions where the majority of the transport studies have been conducted. The climate in the Northern Hemisphere, where the transport studies that have been cited were conducted, would be typically continental with long periods of stable temperatures and winter temperatures in Europe, Canada and the USA frequently being below -10° C for extended periods. Countries such as Mexico and the Eastern States of the USA frequently have prolonged periods where the humidity remains in the 90% range for 24 hours per day for prolonged periods (Wikipedia).

The figures in Table 4, are the average of temperatures recorded by NATIONAL INSTITUTE OF WATER AND ATMOSPHERIC RESEARCH (NIWA) staff between 1981 and 2010 (Macara *et al.*, 2016). The NIWA data shows the climate in Canterbury and was compiled from the average temperature and humidity records taken at a number of different weather stations throughout Canterbury, which included data from both alpine and costal locations. They show that Canterbury has a temperate climate with mild (> 3° C) winters that can have temperatures between 15 and 20° C, and summers that, whilst reaching temperatures in the mid-30s, average temperatures in the mid to low 20s. Whilst the humidity shows distinct seasonal changes, the overall humidity is moderate with an annual range between 55 and 75% relative humidity.

Unlike the findings of Fitzgerald *et al*. (2009), who found the greatest number of deaths occurred during the winter months, some authors have indicated that the period of greatest risk of heat-stress is during the summer months (Cronje, 2007). Using THI values, Heat Maps 2 & 4 appear to confirm the greater risk of heat-stress conditions in summer and cold-stress conditions in winter. However, despite the colder ambient temperatures recorded in winter, pen temperatures reach the high 20s (Table 2) and deaths have been reported during winter months. Whether those deaths were the result of cold-stress or heat-stress is unclear but the high THI values recorded during winter months suggests that heat-stress was the most likely cause.

Studies conducted in Canada and the USA (Brown *et al*., 2011; Ellis & Ritter, 2005) stress the concern for the pigs' welfare during the extreme cold of the northern winters and indicate that more transport-related deaths occurred during the winter months than the summer months. As Tables 2 & 4 demonstrate, the severe cold-stress conditions that are reported to occur in the northern pig-producing regions of the Northern Hemisphere, did not occur during the current study.

Few of the transport studies cited, mentioned the impact that climate or weather had on the study results. As a result, care needs to be taken when interpreting international transport findings, as the changing weather patterns during such studies may not be similar to those that would have occurred in New Zealand.

Weather patterns in Canterbury: Macara *et al*. (2016) showed that the weather in Canterbury can be very changeable with frequent high winds being experienced during November and intermittently through the summer months. Annual rainfall was reported to be low with long dry periods occurring during the summer months. Overall, the weather patterns, as opposed to the continental patterns that occur in the regions where most of the transport studies have been conducted, were typical for relatively small islands that are surrounded by sea and differ from the typical weather patterns that occur in Great Britain (Wikipedia).

The impact of using articulated vehicles for transporting livestock

In the literature cited, only Fisher *et al*. (2004) used a truck that towed a trailer. All of the other field studies cited, either used vehicles with the stock-crate attached directly to the cab or had the stock-crate articulated with the cab and drive unit. In the Fisher *et al*. (2004) paper, the stock-crate was divided down the centre, from front to back, with the sheep that were being monitored being penned on the left-hand side of the vehicle; as a result the findings were not relevant for comparison with the current study.

The configuration of the commonly used New Zealand stock transporters appears to be similar to the type of vehicle that Gilkeson *et al*. (2009) used in their study. It would appear that the 1.7 m gap between the rear of the truck stock-crate and the front of the trailer in a New Zealand-style stock-truck, produces airflows that are different, and possibly less efficient, than the airflows associated with longer, non-articulated vehicles (Gilkeson *et al*., 2009).

Gilkeson *et al*., showed that airflows on the bottom deck of a trailer are lower and more turbulent than airflows on the upper deck. Compromised airflows within the truck and trailer's stock-crates, may therefore explain the high incidence of DOA pigs found on the bottom decks of the truck and trailer crates used in the current study. However, the Gilkeson *et al*. (2009) study only looked at a two-deck construction and the dimensions of the towing vehicle and trailer they studied were different to the size of the truck and trailer used in the current study. As a result of the Gilkeson *et al.* findings, it would appear that a direct comparison with data from international studies based on non-articulated vehicles, may not be appropriate.

It would appear that more studies are needed to examine the impact that towing a multi-deck trailer has on the airflows within truck and trailer stock-crates.

The difference between the environment in the bottom front pen and ambient conditions during the study

The difference between the ambient conditions and the environmental conditions in the bottom front pen can be seen in Table 3. The ambient temperatures reported by W. Thompson (NIWA Research Scientist), were taken from three NIWA weather stations, Christchurch airport, Ashburton and Timaru, from January 2016 to December 2018 (the period of the current study); those weather stations covered the region through which the southbound journeys were undertaken.

The comparison shows that the average temperature in the bottom front pen was consistently higher than the average ambient temperature throughout the year. As was described by Mitchell and Kettlewell (1998), when they looked at heat-stress amongst poultry during winter months, the higher winter temperatures in the bottom front pen may have resulted in the condition that they termed ‘paradoxical heat-stress’.

The pen temperatures recorded in Tables 2 & 3 were taken from the logger attached to the rear wall of bottom front pen during southbound journeys. Incomplete sets of data occurred because the loggers were not installed if there was heavy rain, or the vehicle did not travel to Dunedin after delivering a load of southbound pigs to the abattoir.

The beginning of loading, throughout the study and at both farms, was between 7.30 am and 7.40 am. To reach the farms the vehicle would have been driven, from the overnight depot to the farm, for at least one hour before arriving at either farm so that heat from the motor, conducted through the aluminium wall of the empty stock-crate, could have impacted on the lowest recorded temperatures. The highest temperatures would have resulted from both internal and external heat sources such as from the pigs, the sun and the vehicle’s motor. Wind direction and strength was not recorded during the study, as a result, changes in wind direction and strength may have impacted on the temperature recordings.

The lowest temperatures recorded in Table 2 would have occurred at the commencement of loading when the vehicle was empty. The highest temperatures could have occurred at any point during a journey but would most often have occurred at the end of loading or, occasionally, at the end of a journey when the vehicle had been parked up at the abattoir prior to being unloaded. Table 2 shows that throughout the study period of three years, the range of the highest temperatures in the bottom front pen was 22.60° C to 34.03° C and the lowest temperature range was 2.79° C to 16.03° C giving a variation of 11.43° C and 13.24° C respectively.

The impact that season had on conditions within the four monitor pens: Temperature: In both summer and winter ambient temperatures rose from the beginning of loading to the end of unloading at the abattoir, with the magnitude of the rise being greatest in the summer months when compared with the winter months.

Temperatures recorded on the front wall were consistent between the two seasons reaching the mid-twenties by the time that the pigs had been fully loaded. In summer the variation between the temperatures recorded on the walls was less pronounced than the variations recorded during the winter.

At the beginning of a journey when the stock-crates were empty and starting temperatures were greater than 10^{o} C, the temperatures in all of the pens that were monitored started within $\pm 2^{o}$ C of the ambient temperature. In the winter months, when starting temperatures were less than 5^{o} C, the temperature range was $\pm 1^{o}$ C. Once the motor started the temperature in the bottom front and top front pens rose whilst the temperatures in the other pens remained constant (Graph 6). The greatest temperature fluctuations in all four pens occurred during Winter and Spring.

Except for a few days in the year when ambient temperatures exceeded 32^{o} C, the bottom front pen was hotter than the three adjacent pens. When all four pens were compared, the top front pen was consistently the second hottest pen except on those very hot days when the temperature in the top middle pen exceeded that of the bottom front pen. The temperatures recorded in the top middle pen closely followed those of the top front pen whilst the bottom middle pen consistently remained the coolest of the group.

Within two to three minutes of the vehicle starting to move, the temperature in the bottom front pen began to fall and continued to fall for the first 20 minutes. The temperatures in the other pens followed the same pattern with a greater lag period before the temperatures fell, with the temperature fall being 1 to 2^{o} C less than occurred in the bottom front pen. Temperatures tended to rise in all pens during stationary periods.

<u>Humidity</u>: The bottom front pen had a consistent pattern of moderately high humidities (80 to 90% RH) through all seasons whilst the bottom middle pen tended to record the highest humidities (95^{+}% RH) especially during Autumn and Winter. The top front pen recorded high humidities (90 to 100% RH) during Winter and Spring with lower levels in Summer and Autumn; McGlone *et al*. (2014c) noted that humidity was more important in hot weather. The top middle pen recorded the least number of high humidity events.

It would appear that water vapour was able to move between pens within and between decks. This would suggest that if water vapour concentration was reduced in any pen, water vapour would move from adjacent pens, either from above or beside that pen. Whether this movement was driven by water vapour concentration or by the turbulent airflows described by Gilkeson *et al*. (2009) is unclear.

The humidities, whilst the vehicle was moving, showed the most consistent pattern with the bottom middle and top middle pens having lower high humidity events than either the bottom front or top front pens. When the vehicle was moving the greatest humidity variation occurred during Summer and Winter. Whilst the humidities tended to rise by up to 5% during stationary periods there was little difference between the humidities recorded in all four pens. Graphs 8 and 17 show that as journeys progress the humidity within all pens gradually reduced to levels that were close to ambient levels suggesting that as air flows along the sides of a stock-crate, the venturi effect draws water vapour out of the pens.

Graph 13 shows a greater increase in humidity when the pen was empty when compared with a similar pen that had 14 pigs present. This may have occurred through water vapour, from the fully loaded pen above, diffusing down to the lower pen combining with water vapour emanating from evaporation of moisture that was held in the effluent tank below the floor.

Problems associated with the measurement of ambient conditions in the study

It was noted that anomalous results were occasionally recorded from the logger that was used in the current study to measure ambient conditions; examples are seen in Graphs 2 and 9. It would be expected that over a 30 to 40-minute period when the vehicle was stationary, ambient temperatures and humidities recorded would show very little change being shielded from any heat from the motor or any moisture from rain. However, both temperatures and humidity were occasionally recorded as rising during stationary periods and some inconsistencies were noted when the vehicle was moving.

Whilst humidity rises could have been explained by evaporation of moisture from the linen sleeve that was used to cover the logger (if the sleeve had been damp as could have occurred in foggy conditions), temperature changes could not be so easily explained. The loggers that were used were reported by the company's technical staff to take up to six seconds to record a change in humidity. Thus, the anomalous humidity results could not be explained by a lag period in recording humidity changes inherent in the design of the loggers.

An experiment was conducted to determine whether the temperatures that the loggers recorded were affected by moisture evaporating from the sleeves (evaporative cooling). Four loggers were suspended in front of a fan and a fifth, with a dry sleeve, was mounted behind a fan under still-air conditions. The sleeves of two of the loggers facing the fan, were moistened by steam whilst the other two had dry sleeves; the fan was turned on to produce a moderate air flow for 30 minutes. At the end of the experiment all of the five loggers recorded the same temperatures indicating that the loggers had not been affected by any 'evaporative cooling'.

A possible explanation for the temperature anomalies could be the positioning of the cab relative to the sun. The temperature sensor within the logger (Figure 12) was positioned to face into the gap between the windshield and the cab window. It was anticipated that the back wall of the logger, plus the thickness of the windshield, would block any direct heat from the sun influencing the sensor so the logger would only measure the air temperature in the space underneath the wind shield.

However, it had been shown that the wall of the stock-crate that faced the sun was hotter than the shaded wall. If the temperature sensor was not unidirectional and temperature changes affecting the back wall of the logger were being recorded, it could be expected that the position of the cab, relative to the sun, may have impacted on the data being recorded.

Another reason for the ambient temperatures reported being questionable, is that wind direction and strength were not recorded. It was assumed that the position of the logger, being underneath the wind shield, would have protected the logger from any influence of air movement. However, air movement underneath the wind shield was not monitored and may have impacted on temperature and humidity recordings.

That other researchers have faced the same problem can be evidenced from the number of different locations that they have quoted in the literature. It is worth noting that some of the studies cited (Fox *et al*., 2014; Kephart *et al*., 2010; Haley *et al*., 2010) did not have loggers attached to the outside of the vehicles to record ambient temperatures. Those studies used temperatures recorded at weather stations that were often several miles from the location of the vehicle that was being studied. Other studies (Fiore *et al*., 2009; McGlone *et al*., 2014b; Fisher *et al*., 2004) attached loggers to various parts of the vehicles that were being used.

It would appear that during any future studies a more appropriate location for measuring ambient conditions should be found.

Variables that occurred during the study

<u>*The effect of the weather and seasonal effects during the study*</u>: The major variables that were not recorded during the study were the wind and rain that occurred during journeys. To minimise the impact of the weather conditions, as many journeys as possible were incorporated into each phase of the study and recordings were not taken when heavy rain or snow was predicted.

It was the practice of the driver to adjust the stocking densities during summer and winter by adding or removing one or two pigs per pen as he felt was appropriate at the commencement of journeys; these changes in stocking density were not recorded. Thus, some of the high temperatures during the winter months may have reflected an increased number of pigs in the bottom front pen.

<u>*The variability of fasting times*</u>: Another variable that has not been mentioned in any of the literature that has been cited, relates to the impact that the degree of fasting may have had on heat-stress results. Considering the high-energy modern pig diets and the impact of the pre-journey fasting period on heat-stress (Faucitano, 2013; Cronje, 2005; Brown-Brandl *et al*., 2004), heat radiating from the pigs during the loading periods could be different from study to study, depending on the length of the fasting times.

The diets and ingredients used overseas differ from those used in New Zealand. As a result, one could expect that the heat output from New Zealand pigs may differ from the outputs recorded in overseas studies. This difference could be aggravated by the type of feeder used on the farms that were studied. As has been pointed out, pigs being fed from computer-controlled wet fed systems experience a rapid cessation to their feed intakes after the last feed had been delivered. As a result, the pigs would have become accustomed to the lack of feed after the feed system had been shut off so that any aggression in the interim period would be minimal (personal observation).

However, depending on the farmer, the amount of dry or wet/dry feed that pigs consume once the feed system had been switched off would vary from pig to pig and farm to farm, and therefore from study to study. Pigs tend to become aggressive when there is no feed available so that pre-transport stress levels could be expected to be greater in pigs from dry or wet/dry fed farms when compared with pigs from wet fed farms.

The environment in the bottom front pen

<u>*Positioning of the camera and the visual recordings*</u>: It was necessary to support the video camera in a 'pig-proof' holder that was welded to the stock-crate's frame. For practical reasons, it was only possible to mount the holder against the front wall of the bottom front pen so that all filming was undertaken in that pen.

The position of the camera gave clear views of the pen, however some pigs laid down beside another pig that was sitting up or standing, whilst other pigs might be facing away from the camera, as a result it was not possible to calculate the percentage of pigs that expressed any given stress-related feature at any given time. Despite the difficulty of viewing the mouth of all of the pigs, as a means to estimate the time that pigs started to breathe through their mouths, the videos taken allowed for an estimation of the point at which panting and open-mouth breathing commenced because of the tendency for the pigs to nod their heads up and down when panting. However, when calculating the THI values of the point at which open-mouth breathing was observed, the timing was only taken when the pig's mouth could be observed.

The video's audio function, which picked up the sound of the vehicle's motor, combined with the video recordings of the timing of the images that were taken, allowed for the precise timing of any events that occurred in the bottom front pen and these could be compared with the times that the driver had recorded.

Visual evidence of transport stress: The anticipated behavioral evidence for transport stress were facial expressions associated with anxiety, incessant pacing or wandering, aggressive interactions between pigs expressing irritability, high pitched vocalisations expressing distress (Dokmanovic *et al.*, 2014) and/or increased respiration rates and open-mouth breathing.

Visual observations were made throughout the study to record the impact that changing conditions had on the welfare of the pigs and how the pigs responded by changing their posture by lying down or standing. The visual observations were also needed to determine the point at which open-mouth breathing commenced, which has been taken to indicate the commencement of heat-stress (Benjamin 2005; Eigenberg *et al*., 2005; Gaughan *et al*., 2000; Hahn *et al*., 1997).

By the time that the first pigs arrived at the bottom front pen they showed clear signs of stress, with anxious expressions and respiration rates being higher than normal, though little panting was evident. There was relatively little room for the pigs to move once they were shut in the pen, a situation that may have explained the finding that aggressive behaviours appeared to be inhibited in the period after loading. However, the stress-signs that did occur diminished over time so that within 20 minutes of arrival in the pen there were few signs of antagonistic behaviour.

During southbound journeys, once all 14 pigs reached the bottom front pen, they were shut in by the driver closing the pen gate and lowering the upper floor to create a ceiling. Whilst the camera recorded activities within the bottom front pen, no further images were available that recorded the arrival of later groups of pigs. Whilst wall temperatures often had considerable variability, the pigs showed no particular preference to where they stood or laid down.

In northbound journeys the first pigs to be loaded were penned on the second deck before the lower deck was loaded. The pigs on the lower deck were not shut in but were loosely loaded at a density of 14 pigs per pen, this allowed the camera to record some of the activity in the middle and rear pens. In the northbound journeys, pigs tended to spread out evenly between pens but occasionally were seen, for no obvious reason, to gravitate to the middle and rear pens.

After the first group of pigs had been loaded into the bottom front pen (during a southbound journey), subsequent pigs moved more rapidly and with less investigation, and thereby less encouragement from the driver, as they travelled towards the pigs already on board. The loading-stress levels of the pigs therefore varied according to their location, as can be seen by the different THI levels recorded between the bottom front and bottom middle pens (Table 4), with pigs in the bottom front pen and the pigs in the pen immediately above it experiencing the highest THI levels.

Heat map 4 and Graph 9 show that THI levels rose during the loading and mid-journey stationary periods. These findings appear to support the findings in other studies that suggest that heat-stress increases during stationary periods.

The stress levels associated with the loading of the pigs in the current study may have been different to the stress levels reported in the literature. Apart from the pot-bellied vehicles that were reported in the literature, that have been shown to create the greatest loading stresses for pigs, the majority of the vehicles described in the literature were 14 to 15 m long compared to the study vehicle that was 7.2 m long. It would appear likely that loading a single long deck would be less stressful for pigs than loading a shorter truck and trailer unit as was used in the current study. As Grandin (1980) noted, loading stresses will vary from farm to farm and therefore from study to study.

As suggested by the point raised by Grandin (1997), it also appeared that the novelty of the new environment within the transport vehicle may have impacted on the natural instinct for the pigs to establish their hierarch. Brunjes *et al*. (2016) and Lewis *et al*. (2010) pointed out that the pigs' acute sense of smell can have a significant effect on their behaviour whilst Kephart *et al*. (2014) remarked on the potential significance of fear pheromones, released in a pig's urine, as a contributor to loading stresses.

The vehicle used to transport the pigs in the current study was used to transport sheep and cattle between the weekly pig runs. Whilst the vehicle was hosed out at the end of each day faecal material from sheep or cattle was always present on the walls (Figure 4) and in the truck's effluent tank. Apart from the physical surroundings, it could be expected that the smell of animals that were not familiar to the pigs may have been disconcerting to the pigs, thereby altering their natural tendency to aggression. Such a situation would not have been present in the single-species vehicles used in the studies that have been cited.

It was thought that the relative lack of aggression amongst the southbound pigs may have also been related to the fact that they had lived together as a group before being loaded and had established a stable hierarchy pre-loading. During the northbound journeys the pigs had freedom to move around the bottom deck of the truck and thereby a greater opportunity to assert their hierarchy than pigs in the southbound journeys. The northbound pigs had been assembled from different social groups immediately before transport and would have needed to establish their hierarchy once on board the vehicle. Graphs 10 & 11 show that the loading stress (as suggested by the rapid rise in THI levels) experienced by the northbound pigs was greater than the loading stress levels experienced by the southbound pigs. The video images confirmed that there was more aggression seen amongst the northbound pigs than the southbound pigs.

During the majority of the journeys the pigs remained standing throughout the loading period and only began lying down once the vehicle started moving. When the vehicle stopped the pigs showed curiosity behaviour with some peering out through the wall openings and others rising and moving around the pen. After a brief period, the pigs settled down with the majority lying in lateral or sternal recumbency throughout the stationary period. Lying down in lateral or sternal recumbency would have provided more air space above the pigs allowing for better air flows from the wall openings than would have occurred if all of the pigs had remained standing. Lying down could also have been due to the pigs wanting to benefit from the cooling effect of the wet floor and the capacity of the metal to conduct heat away from their bodies. Thus, lying down may not have been a sign of contentment but could have been a response to adverse environmental conditions.

Occasionally some pigs were seen, when THI values were below 70 (i.e. presumed to be unrelated to heat- stress), to drool saliva from their mouths whilst having a distressed expression on their faces. This behaviour was construed as being caused by the pigs suffering from motion sickness (Marchant-Forde & Marchant-Forde, 2009; Warriss, 1998a; Bradshaw *et al.*, 1996b), however, no vomiting was recorded during the study. Dalla Costa *et al*. (2017) suggested that motion sickness may be associated with vehicles that have leaf-spring suspension as opposed to vehicles with air suspension. The vehicle used in the current study had air-suspension, which may have contributed to the low incidence of motion sickness recorded during the study.

<u>*The presence of noxious gases*</u>: It was noted that when the pigs were seen to be lying down on the bottom deck there was no evidence of lachrymation, coughing or respiratory distress that might have occurred

had there been significant levels of ammonia or other noxious gases emanating from the effluent that was immediately below their noses. The driver commented that ammonia levels noted during unloading, were more commonly experienced when unloading sheep. It would appear that the diet and monogastric digestive system of pigs does not produce the levels of ammonia that are commonly associated with ruminant digestion (Wathes *et al*., 2003).

<u>*Cold-stress*</u>: In the winter months it was too dark to see the pigs clearly until around 8.00 am. However, during the northbound load-outs, because the truck was parked next to a major highway, the headlights of passing vehicles gave brief views of the pigs as the light entered through the wall openings allowing assessment of the effect of cold-stress on the pigs. Observations made during the loading of the northbound pigs, showed that pigs huddled together for the first 15 to 20 minutes before they separated and reduced body contact. Because the views of the huddling behaviour were intermittent, it was not possible to establish the temperatures at which the separation of body contact occurred.

Schrama *et al*. (1996) noted that '*As long as hypothermia does not occur, cold-stress is of minor importance for the mortality rate during transport*'. However, since pigs were reported to shiver when they were subjected to cold conditions (McGlone *et al*., 2014a; Newman *et al*., 2014; Hoff, 2006), it would appear that their welfare had been compromised. No references could be found to indicate the temperature at which shivering commenced and thereby the point at which an animal's welfare had been compromised by cold-stress.

The impact that loading had on the temperature, humidity and THI levels in the bottom front pen

When looking at the environment within the bottom front pen, temperatures and humidity levels were taken from the logger attached to the back wall of the pen to minimise the impact of any heat from the motor would have had on the logger that was attached to the front wall of the pen.

The environment in the pens within a stock-crate is a combination of external factors (sun, wind, rain and heat from the truck's motor) plus the heat and humidity produced by the pigs and any humidity or gases arising from evaporation of liquid held in the effluent tank. The liquid in the effluent tank also contributes a variable thermal mass depending on the volume of fluid that it contains. Movement of the pigs, combined with any air flow created by wind entering the pen through the wall openings, plus the efflux of air through the wall openings caused by the temperature differential between the inside and outside of the stock-crate, would create a constantly varying environment within the pens. Thus, the process of loading would rapidly change the environment in the bottom front pen (the first to be loaded) from conditions that would have been close to the ambient conditions at the start of loading (Graph 2 & 11). At the end of loading the pen temperatures were always greater than the ambient temperature with the relationship between the ambient and pen temperatures varying from journey to journey.

<u>*Temperature*</u>: During the first five minutes, there were no pigs in the pen so that all of the loggers recorded similar data. Of note was the observation that the temperature beside the rear wall of the pen was higher than the ambient temperature. Since the back-wall logger was shielded from any effect from the sun or wind, this finding was construed as indicating the impact that heat from the motor and catalytic converter had had on the back wall.

At the end of the first five-minute period pigs started entering the pen and milled around disturbing the air within the pen. This process took two to three minutes and resulted in a spike in all of the data being recorded. This temperature fluctuation may have been caused by an efflux of air through the wall openings or may have been due to mixing of the air within the pen.

Unlike pens on the upper deck, the ceilings of the bottom deck pens would not have been affected by solar radiation because the floors of the upper pens would have shielded the lower pens. However, as seen in Graph 6, it would appear that after pigs had been loaded onto the second deck, heat from those pigs may have contributed to the continuing rise in the temperature in the bottom front pen. This could have impacted on the temperatures recorded in all of the lower pens during loading.

The degree of the solar heating of the upper deck pigs would be variable because both of the south and northbound journeys started early in the day when the sun was low on the horizon and were completed mid-day when the sun would be at its zenith. Graph 16 shows that the temperatures recorded on the top deck, as the journey progressed, were greater than those recorded on the lower deck, suggesting that heat from the sun and from the pigs on the lower deck may have affected the environment of the pens on the upper deck. Gilkeson *et al*. (2009) reported that six times more air passes through the top deck compared with the bottom deck at all vehicle speeds.

From the start to the finish of loading, the heat created by the presence of the pigs caused a steady rise in the temperature within the pen. Despite wall temperatures occasionally reaching greater than 30^{o} C, there was no evidence to suggest that pigs showed any preference for which wall of the pen they stood or laid against. At no time did any pig show the desire to use the wall openings to improve their respiratory comfort although, from time-to-time, some of the pigs peered out through the openings. The place within the pen that pigs chose for resting appeared to be dictated by social interactions rather than by ambient conditions.

Graph 5, referring to conditions at the start of the day when the truck was empty, shows that whilst the bottom front and top front wall loggers, attached to the front walls of each pen, recorded a temperature rise once the motor started, the loggers on the back wall of the pens did not show a similar temperature rise. It was noted that when the truck arrived at the farm empty, the temperature recorded on the front wall of the bottom pen was 1-2^{o} C higher than the ambient temperature. Since the front wall was shielded from any solar radiation, it is proposed that the above findings indicated that heat from the motor had been conducted through the aluminium wall cladding and influenced the air surrounding the front wall of the pen.

Graph 14, referring to the difference between having either ten or 14 pigs in the bottom front pen, showed that when the pen was empty there was a temperature rise of 8° C during loading. This suggests that temperature changes within a pen may have an effect on adjacent pens so that the environment in any pen cannot be measured in isolation but should reflect conditions in adjacent pens.

Humidity: The humidities recorded in all four pens varied between journeys so that a consistent pattern was difficult to establish. There was little evidence of a seasonal pattern to the humidities recorded during loading, moving or when the vehicle was stationary.

In the empty vehicle, at the commencement of a journey, the humidities in all pens followed the general pattern of the ambient humidity. At the commencement of a journey, when the vehicle was loaded, the humidities recorded in the lower pens were higher than those in the pens above them. As the journey progressed the humidity in the upper pens rose relative to the humidity in the lower pens. During loading, before the motor started, the pen humidities were 10 to 15% higher than ambient but that difference increased, and stabilised, as the loading progressed.

After five minutes from the time that the first pigs entered the pen the humidity within the pen began to climb. Within 15 minutes of the first pigs entering the pen the humidity rose from ambient levels to 95+% and then remained steady throughout the remainder of the loading period. It was notable that the humidity peaked more rapidly than the temperature and remained constant whilst the temperature within the pen continued to climb until the vehicle started moving.

As with the temperature changes during a journey, the humidity changes were found to be greatest during the period in which the pigs were being loaded (Graph 6). These changes could be expected when one considers the physical activity and stress that the pigs would have experienced during the period preceding the loading.

When the truck was carrying no pigs at the beginning of a journey (Graph 6), the humidity rose in the two bottom-deck pens; it should be noted than in Graph 6 the top-front logger malfunctioned. This rise suggests that the humidity in a stock-crate may be affected by the evaporation of water from condensation on the walls of the stock-crate and/or water that was held in the effluent tank under the floor.

Graph 13, referring to the difference between having either ten or 14 pigs in the bottom front pen, showed that the relative humidity in the empty pen rose by 20% during loading. Since the rise in humidity followed the same pattern as occurred during the loading of the 14 pigs, this suggests that water vapour can diffuse from one deck to another during journeys despite the tight-fitting ceilings.

THI calculations: Whilst THI levels can, at best, only be an indicator for heat-stress, such values have become accepted in the scientific literature as reliable indicators for heat-stress conditions.

The data recorded for the THI calculations only indicated the THI levels immediately surrounding the point at which the loggers had been mounted. A mathematical model was developed that indicated, with a 97% degree of certainty, that the logger on the back wall gave the best indication of the average THI levels within the pen; its relevance was not validated in other pens. As a result of this finding, THI comparisons between the bottom front pen and other pens were taken from the loggers attached to the back walls of the pens being studied. THI levels calculated for the period in which the pigs were being loaded (Graph 9 and Heat Map 4) reached levels that exceeded the THI levels calculated for any other segment of the journeys.

When comparing THI levels recorded on each of the pen walls it was noted that the levels calculated for the back wall were greatest in that part of the pen during loading. Since THI calculations are strongly influenced by temperature it is possible that heat from the pigs in the middle pen, conducted through the thin aluminium pen-partition, may have influenced the back-wall calculations of the front pen. There was no discernable relationship between the THI levels recorded within the pens and the ambient temperatures that were recorded, indicating that ambient temperatures were not the driving force behind the changes in THI levels within the stock-crate when it was loaded with pigs.

It was noted that individual pigs commenced open-mouth breathing when the THI reached between 71 and 72 and that more than one pig would be breathing through its mouth by the time that the THI reached 73. From this observation it is proposed that, under the conditions of the current study, heat-stress (as indicated by the appearance of open-mouth breathing) commenced when the THI reached 73; this is consistent with findings in the literature (Vitali *et al*., 2014; Hahn *et al*., 2009; Armstrong, 1994) but differs from the levels reported by Fisher *et al.* (2004). Vitali *et al*. (2014) reported that a piecewise analysis of their THI data showed that the thresholds above which the mortality rate increased for DOA and DIY pigs was between 73.6 and 78.5.

Fisher *et al*. (2004), studying sheep transport, used a formula for the calculation of the THI levels that was developed for use with cattle (Fiore *et al*., 2009). As Fiore *et al*. (2009) noted, THI formulae are species-specific so that it is possible that the levels reported by Fisher *et al*. (2004) were not appropriate for sheep, or that the sheep stress-levels calculated from THI levels may be different to the stress levels in pigs. This finding indicates that care should be taken to establish the formula used to calculate the THI levels when comparing THI levels between studies.

The environmental changes that occurred within pens during journeys

Temperature: Once the vehicle started moving the temperatures on all four walls of the bottom front pen declined, with the temperature decline increasing with journey length; side-wall temperatures were affected to a greater extent than end-wall temperatures. Graph 3 shows that whilst the wall temperature variation rose during loading, as the journey progressed, temperature variations within the pen diminished but remained high.

As was seen in the video recordings, it appeared that prior to the mid-journey stationary periods, pigs relaxed ('habituated') and became accustomed to the vibration, movement and noises of the vehicle when it was moving, as suggested by Hambrecht *et al*. (2005a). However, it would appear to be a moot point whether pigs lying down was evidence of pigs 'relaxing' or whether such posture was evidence that the pigs were attempting to cool themselves.

Humidity: Unlike the temperature changes, which remained consistently above the ambient temperature throughout the journeys, the humidity on all four walls of the bottom front pen stabilised 15 to 20 minutes after the vehicle started moving and closely followed the ambient humidity until the pigs were off-loaded at the end of the journeys. Graph 6 shows a marked difference between the humidities recorded beside the sidewalls of the pen. It would appear that such differences could be the result of wind or external air movement affecting the outflow of air from the vehicle. Mitchell & Kettlewell (2008) commented that internal airflows were primarily driven by the effect of wind.

As Kettlewell *et al*. (2001a) pointed out, it would appear that water vapour was being drawn out through the wall openings when the vehicle was moving, reducing the humidity within the stock-crates. As was indicated by the fall in the THI levels seen in Heat Map 4, the reduced humidity within the pens would allow for more effective evaporative cooling of the pigs, leading to a marginal lowering of body temperatures.

THI: When the vehicle was moving, THI levels fell with the level in the bottom front pen continuing to be the highest and the level in the top front pen following closely. As seen in Heat map 4, as journeys progressed THI levels fell, after reaching their highest level at the end of loading, and then became static, but high, through to the end of the journeys.

The pattern seen in most journeys indicated that the top middle pen had higher levels than the top front pen. It was considered that air over the top front pen was more turbulent than over the top middle pen, as was indicated by the computational model of Norton *et al*. (2013). Whilst the top pens were equally subject to heat from the sun, when the vehicle was moving the turbulence over the top front pen would have the effect of reducing the heat relative to the top middle pen. However, it would appear possible that the position of the top-front logger, against the front wall of the pen, may have shielded the logger to a greater extent than the logger in the top-middle pen, potentially leading to lower temperatures being recorded.

Graphs 9 to 11 show that during the stationary periods associated with loading and mid-journey breaks, the THI levels rose, suggesting that heat-stress conditions increase during stationary periods.

The impact of the vehicle's speed: An important factor affecting air movements within the pens in a stock-crate, is the speed of the vehicle (Norton *et al*., 2013; Gilkeson *et al*., 2009; Lenkaitis *et al*., 2007). Universally, the speed of vehicles in residential areas is restricted whilst the speed on open-roads varies from country to country. Depending on the relationship of the packing plant or abattoir to the farm, air movement within the stock-crate, resulting from the speed of the vehicle, will vary from study to study.

Another factor that needs to be considered when comparing study results is that the speed of a vehicle will be affected by the topography of the region through which the vehicle travels. The current study looked at two journeys with contrasting topographical features (Graphs 10 & 11). Whilst the impact of the steep inclines that were negotiated during the northbound journeys could be recognised (Graphs 5 & 6), other factors such as the changing diurnal temperatures, the length of intra-journey stationary periods and the vehicle's speed through residential areas, meant that when contrasting the stress levels between any two journeys, the effect of the route taken and topographical features should be considered.

Another consideration, relating to the topographical features of a journey, is the impact that heat from a vehicle's motor will be have on conditions within the front pens of a stock-crate when the vehicle negotiates steep gradients. It could be expected that heat from a motor would increase when a loaded vehicle negotiated a steep incline.

The impact of wind speed: Fitzgerald *et al*. (2009), noted that '*The presence of wind can be beneficial during hot weather and dangerous to animal welfare during cold weather if proper precautions are not taken'.* Whilst the statement related to the road transport of pigs, it appeared to be directed at the problem associated with 'chill factor' during the extreme cold in winter in the north of the USA. The authors quoted Mader *et al*. (2006) who reported that an increase in wind speed by 1m/second decreased THI by 3.14 units. Whilst the Mader *et al*. (2006) study was conducted on cattle in a feedlot, it did show that airflows over an animal's body surface can impact on the heat and humidity that the animal experiences.

Mader *et al*., (2004), quoting Robertshaw (1985), stated '*Increased air movement over the body surface results in the disruption of the layer of air near the skin surface. Disruption of this airspace allows for the removal of warm air being replaced by this cooler air. Body heat of the animal is then transferred to the cool air and removed via continuous air movement.*'

Unless a wind was very strong, it would appear unlikely that the wind would have a significant effect on animals within a stock truck when the vehicle was moving. However, when a loaded vehicle was stationary, depending on the wind's direction, the air entering the stock-crate through the wall openings, could have either a positive or negative effect on the animals' welfare. No studies in the literature cited, commented on wind direction or strength.

The impact of mid-journey stationary periods

The significance of the impact that the length of mid-journey stationary periods has on the welfare of stock will become increasingly important as more countries require drivers to have such breaks for work-safety purposes. In July 2013, the UNITED STATES DEPARTMENT OF TRANSPORTATION introduced an 'hours-of-service' safety regulation that required truckers to have a 30-minute break, away from their trucks, after eight hours of driving (Kephart *et al*., 2014). In New Zealand drivers are required to have similar breaks. In general, in New Zealand, drivers must take a break of at least 30 minutes after five and a half hours of working, no matter what type of work takes place during that period.

The transport regulations in New Zealand state: '*In any cumulative work day you may work for a maximum of 13 hours and then you must take a continuous break of at least 10 hours (as well as the half hour breaks every 5 ½ hours). A cumulative work day is a period during which work occurs, and that does not exceed 24 hours; begins after a continuous period of rest time of at least 10 hours; you can accumulate a total of 70 hours work time (known as 'cumulative work period') before you must take a continuous break of at least 24 hours.*'

Several references to transport stress in the literature focus on the impact that stationary periods have on changes in temperature and humidity within a pen (Xiong *et al*., 2015; Kephart *et al*., 2014; Nannoni *et al*., 2014; Norton *et al*., 2013; Mitchell & Kettlewell, 2008; Fisher *et al.*, 2004). The bulk of those references referred to the period during which pigs were being loaded on or off a vehicle with little mention of the impact of transport stress during mid-journey stationary periods. Xiong *et al.* (2015) found that mid-journey stoppages led to a rapid increase in the temperature within stock trailers with a 3 - 4° C rise within five minutes.

Norton *et al.* (2013) and Fisher *et al.* (2004) looked at mid-journey stationary periods with relationship to Roll-On-Roll-Off ferries. Whilst all of the references indicated that temperatures rise during stationary periods, with the period during which animals are loaded having the greatest impact, no references could be found that looked at changes in humidity.

The study by Norton *et al*. (2013) involved the examination of stationary-period stresses in a confined space (between the decks of a Roll-On-Roll-Off ferry) and were therefore not directly comparable to the current study. However, the study by Fisher *et al*. (2002), whilst monitoring the impact on sheep, was undertaken in an open environment and supports the findings from the current study by showing that during such stationary periods the temperature rises within pens when stock were on board.

There is considerable variability in the wide range of loading-stresses that pigs experience from the time that they leave the pens on the farms to the time the vehicle first starts moving. As a result, it was considered that comparing the impact of heat-stress during mid-journey stationary periods would give a more reliable indication of the impact that stationary periods had on heat-stress, than comparing the effect of stationary periods associated with the loading or unloading of the vehicle.

Some authors (Brown *et al*., 2011; Marchant-Forde & Marchant-Forde, 2009; Ellis *et al*., (2008); Fisher *et al*., 2002) have pointed out that pigs on the top decks of vehicles will have the additional input of heat from solar radiation and that heat from the sun can also affect pigs in the lower decks due to conduction through the walls of the stock-crate. However, other authors (Weschenfelder *et al*., 2013; Kephart *et al*., 2010), whilst noting the increased heat-stress on the top deck of transport vehicles during the summer months, focused on the exertional heat-stress caused by the pigs climbing internal ramps within the stock-crates.

Mitchell & Kettlewell (2008) state that '*The carriage of large numbers of closely packed animals will result in the addition of a great amount of heat and water vapour inside of the vehicle during transportation'.* In their study, that involved a two-hour mid-journey stationary period, they found that the temperature in the deck of the transporter that held 75 pigs, rose from 9.5 kW to 22.3 kW and the water vapour rose from 1.7 g/s to 3.9 g/s; they noted that some of the moisture would have been derived from urine and faeces. They concluded that pigs of 100 kg bodyweight can be expected to generate approximately 1.5 W/kg and 0.003 g/s/kg of water when a vehicle is stationary.

The effect of stationary periods during the current study

Temperature: During stationary periods, unless wind enters the pens through the wall openings, heat and water vapour can only be dissipated, passively, through the wall openings making the size and configuration of the wall openings crucial for the comfort of pigs during stationary periods (Randall & Patel, (1994).

The current study found that, whilst the temperature in all four pens rose during mid-journey stationary periods, the effect was not as pronounced as was seen during loading. After being stationary for 40 minutes, the temperature in all four monitor pens, whilst higher than at the beginning of the stationary period, reduced to a point where there was only a 1° C difference between the pens.

At the end of the mid-journey stationary periods, despite the temperatures in the upper pens being influenced by the sun, the bottom front pen continued to record the highest temperatures (Table 8, Graph 7). This finding suggests, as was pointed out by Gilkeson *et al*. (2009), that air flows within the upper pens may be greater than the air flows in the lower pens, allowing for more efficient cooling of the pigs. Kettlewell *et al*. (2001a) found that during stationary periods water vapour exited the pens through the wall openings leading to a drop in humidity, but pen temperatures were largely unaffected.

As Fisher *et al*. (2004) found, not all of the stationary periods that were monitored during the study recorded increases in pen temperatures (Graph 10); as in the Fisher *et al*. study, a cause could not be found in the current study. However, despite those findings, the welfare of stock on the top deck of a transporter during prolonged stationary periods in summer, may be compromised. Not only would the stock be subject to the high ambient temperatures but, unless an appropriate screen is put in place, the stock may be subject to sunburn.

Humidity: During mid-journey stationary periods the humidity on all four walls rose with the side walls showing greater fluctuations than either the front or back walls; once again, suggesting that water vapour was exiting the pens through the wall openings. As previously stated, Kettlewell *et al*. (2001a) pointed out that the efflux of air during stationary periods has a greater effect on the humidity within the pens than on the pen temperature.

After the stationary period, when the vehicle started moving again, the variation in the wall humidities diminished such that after 30 minutes there was less than a 10% difference between any of the walls; Lenkaitis *et al*. (2007) reported similar changes. At the same period the wall humidities became closely aligned to the ambient humidity.

In an attempt to demonstrate this air movement, lengths of knitting wool were taped to the outside-wall above the openings (during a mid-journey stationary period), so that the threads draped downwards over the openings. During the stationary periods the wool fluttered outwards showing that there was an efflux of air from the pens through the openings.

THI: Of the 14 pens that were loaded with pigs, the study only monitored five pens, four on the truck unit and one on the trailer unit. Based on the DOA incidence found in the pre-study report from the abattoir, the four pens on the truck-unit recorded the highest number of dead pigs, suggesting that these were the most stressful pens. In the literature, the pens that were reported to be the most stressful varied, however, the studies cited involved vehicles that had different configurations to the vehicle used in the current study. Whilst it would appear reasonable to assume that the monitor pens in the current study would experience stressful conditions in a New Zealand-style stock-truck, the level of stress in the pens that were not monitored, is unknown.

During mid-journey stationary periods, it was found that THI levels climbed and occasionally reached critical levels during both summer and winter months (Graph 9). The longer the stationary period the greater the THI levels reached. This effect was particularly pronounced if delays occurred when the pigs were due to be unloaded at the abattoir.

Table 8 shows the location of monitor pens that were susceptible to heat-stress as indicated by elevated THI levels. THI levels greater than 71 were noted in some part of the stock-crates on 62% of the journeys. 41% of the elevated THI levels occurred in pens on both decks with the incidence close to being evenly distributed between the two decks. Whilst on 24% of the occasions the elevated THIs only occurred on the lower deck, 17% of the occasions occurred only on the upper deck. This indicates that, despite the anticipated better airflows on the upper decks, that would assist pigs to keep cool, there is a potentially significant solar heat-stress problem on the upper decks.

The pre-study report showed that the bulk of DOA pigs were found on the bottom decks of the truck and trailer stock-crates. The finding that 17% of the elevated THI events only occurred on the top deck may indicate that the level of humidity, that was consistently lower in the top deck pens, may be an important contributor to the low level of fatalities that were recorded.

In New Zealand it is normal practice for drivers to close the floor above the pigs on the top deck to create a ceiling above those pens. This is done to avoid the problem of pigs trying to climb over the inter-pen partition and to protect the pigs from sunburn and inclement weather. Since the aluminium floors conduct heat from the sun and are situated close to the pigs, it would seem that the pigs' welfare could be improved during hot weather, by using the flexible covers that are attached to the top of the crate walls, rather than closing the metal floors.

The issue of airflows on the top deck of transport vehicles raises the question of the potential difference of overseas findings to New Zealand conditions. The majority of vehicles in the Northern Hemisphere, particularly those in the northernmost countries such as Canada (from the literature cited and personal observation), have a solid roof fixed to the side-walls, over the top deck. Ventilation within the stock-crates would therefore be solely from air entering and exiting through the wall openings, potentially making the airflows within the vehicles different from New Zealand-designed vehicles.

Factors that could have affected the degree of heat-stress experienced by the pigs during the study

<u>*Ambient temperatures*</u>: The pig's upper critical temperature, as measured by core body temperature, is considered to be 24° C (Schrama *et al*., 1996), above this temperature the pig must attempt to reduce its temperature by such mechanisms as wallowing or panting to improve evaporative heat loss. Pigs will often wallow in their own urine as a means to cool themselves but the drainage through the floors in stock-crates limits the opportunity for this process to take place leaving open-mouth breathing as the primary mechanism for reducing heat-stress within the confines of a stock-crate.

In New Zealand ambient temperatures often exceed 24° C (Table 2) so that there would appear to be a need to provide some means for reducing the environmental temperatures that pigs experience during transport, on a majority of journeys. The point at which mechanisms need to be applied to mitigate the effect of heat-stress in pigs has been debated in the literature, it is apparent that when ambient temperatures reach the mid-twenties, some form of relief such as mechanical ventilation or water spraying will be required. Table 3 shows the number of times that the pigs experienced temperatures that exceeded their upper critical temperature.

The range of ambient temperatures recorded during loading in the current study was from 2.79° C up to 34.03° C (Table 2); however, the lowest temperature recorded during the study, when the truck was empty at the start of a northbound journey, was -3.5° C. With such a wide range of temperatures passive ventilation systems run the risk of exposing stock to either cold or heat-stress. Whilst cold-stress conditions were noted during the winter months, particularly at the beginning of loading, the periods were brief. Long periods of cold-stress, such as are reported in the literature, were not seen during the current study. It was also noted that the winter temperatures recorded during the current study did not fall as low as has been recorded in the literature (Fitzgerald *et al*., 2009; McGlone *et al*., 2014b).

The effect of diurnal temperature changes: As the journey progressed diurnal temperature increases impacted on the ambient temperature recordings. Because loading started early in the morning and off-loading at the abattoir occurred mid-day or early in the afternoon, the ambient temperatures that were recorded rose steadily throughout all journeys. This pattern was most apparent when temperatures recorded during southbound journeys were compared with those of the northbound journeys (Graphs 10 & 11). Because the northbound journeys were longer than the southbound journeys, off-loading occurred in the early afternoon, when daily temperatures had peaked, rather than prior to noon, as occurred in the southbound journeys. This suggests that, as occurs in some countries, the time of loading could be changed during the hottest months of the year so that pigs were off-loaded early in the morning when conditions were cooler. However, local body regulations, that will vary from region to region, may restrict the movement of heavy vehicles in the early hours of the morning.

The effect of season: Table 3, produced from NIWA weather station reports, indicates that the temperatures during the study period were typical of a temperate climate. Temperatures in Canterbury, over the three-year period of the report, ranged from 5.9 to 17° C with the anticipated humidity (Table 4) ranging from 54 to 72%. The majority of the transport studies cited were conducted in countries where continental climates, characterised by extended periods of stable weather patterns, prevailed.

Summer: On hotter days in summer the pen temperatures followed the ambient temperatures. However, in winter and on colder days, the temperatures within the pens tended towards greater variability and less relationship to the ambient temperatures. A noticeable seasonal impact was the greater variation between the side-wall temperatures during the winter when compared with the warmer autumn temperatures.

Heat map 3 shows the seasonal effect on temperatures in the bottom front pen. In summer, when the ambient temperature rose from 15° C to 17° C, the temperature on the front wall of the pen rose from 15° C to 21° C showing that assessing potential stress levels based on ambient temperatures could be misleading. This problem was further emphasized by the winter temperatures when the ambient temperature fell from 10° C to 4° C whilst the front wall of the pen rose from 9° C to 22° C.

Winter: Of particular interest was the number of times that heat-stress conditions occurred during the winter months. Because data was not collected during periods of rain or snow, particularly during the Autumn and Spring months, the impact that colder or wetter weather conditions had on heat-stress could not be determined. Visually, the pigs that were videoed during the winter months in the current study, showed little sign of discomfort, with the exception of a short period immediately after they had been loaded.

The effect of the size of the pigs: Data from the literature show that overseas stock transporters carried pigs that were on average 20 kg heavier than those carried in the current study. Brown-Brandl, (2004), reported that heavier pigs produce more body heat than smaller pigs and that the heat production between 60-100 kg may be as much as 1 W/kg. Kettlewell *et al.* (2001b), reported that pigs of 100 kg produce 200 W heat per animal and that these levels increase during stationary periods.

That the size of pigs has increased in New Zealand over the past few years can be seen from Graph 1 (Chapter Two), if the trend continues, the transport of more and larger pigs could be expected to have a negative impact on the space allowances required to provided optimal welfare for the pigs being transported.

The effect of the gender of the pigs that were transported: Transporting entire male pigs could be expected to have resulted in a high level of aggressive interactions within the pens during journeys. However, in the current study there were very few video recordings showing fighting, with aggressive interactions being more related to ear-chewing or neck-biting, suggesting irritability rather than aggression. It would appear that the limited space within the pens, and possibly the novelty of the environment, may have contributed to the small amount of aggression that was recorded.

Castration, either chemical or surgical, can affect a pig's behaviour and physiology, particularly the amount of subcutaneous fat. None of the papers cited reported on the number or ratio of barrows to males or females being transported. However, such ratios may have impacted on results and would have been different to results in New Zealand where castration is not allowed.

The effect of a pigs' posture: Whether pigs are standing or lying down is often taken as an indication for the pigs' state of contentment, however a pig's posture during transport may be a greater indicator of its response to the environment within the stock-crate. Several authors (Becerril-Herrera *et al*., 2007; Bradshaw *et al*., 1996a) have indicated that whether a pig stands or lies down can affect the pig's temperature. The standing position may be a response by the pig attempting to avoid lying on a cold floor surface (Goumon *et al*., 2013). The standing position requires muscular effort that creates heat to maintain that position, therefore the standing position may be the result of either a psychological or a homeostatic response to environmental conditions.

When a pig lies down in lateral recumbency a large part of its body surface is exposed to the cooling effect of a floor that results from body heat being conducted away from the pig by the aluminium or steel mesh flooring. Another consideration is that the floor is likely to be dampened by urine which could lead to an opportunity for increasing evaporative cooling. A further consideration is that when the pig is lying down there is an increase in the amount of air space above the pig that would allow for more air movement above the pig, also increasing the opportunity for increased evaporative cooling.

During loading, pigs tended to stand until loading was completed and then laid down during the time that the vehicle started moving. The postural change may therefore have been a response by the pigs to cool down rather than an expression of relaxation after the stresses they experienced during the loading process.

The effect of stocking density: Data was collected during five southbound journeys that had been selected for their having similar ambient conditions. Because of the risk that if the numbers of pigs in the pen were too small the pigs might be injured during transport the minimum group size was set at ten pigs; the conventional stocking density of 14 pigs per pen was used for comparison.

Overall, the data indicated that as stocking densities increased, both the temperature and humidity and, as a consequence, THIs within the pens increased. The findings also suggested that water vapour in the pens can migrate to other pens despite the apparently water-tight ceilings separating the decks.

The images taken by the camera showed that at both stocking densities (ten versus fourteen) the pigs appeared comfortable and that at the lower stocking density the pigs were able to maintain a stable position when standing.

Temperature: Because of the limited numbers of observations and the variables associated with analysis, the data in Table 4 could not be taken to represent statistically meaningful results. However, Table 4 indicated that when ten pigs were in the pen the temperature rose by 5.5° C which is equivalent to 0.55° C/ pig.

Graph 12 compared two journeys where one journey had 14 pigs in the bottom front and bottom middle pens and the other journey had the bottom deck empty. The graph indicated that when there were 14 pigs in the pens the temperatures in the pens rose relative to the ambient temperature with the effect in the bottom middle pen being less than in the bottom front pen. By contrast, when the bottom deck was empty, the pen temperatures followed the pattern of the ambient temperature rise. However, care needs to be taken when interpreting the results as temperature and humidity in the empty deck may have been influenced by conditions in the upper deck.

The results shown in Graph 14, where the effect of having ten pigs in the bottom front pen was compared with having 14 pigs in the pen, were compromised by having 14 pigs in the bottom middle pen so heat from the pigs in the bottom middle pen may have influenced the results in the bottom front pen when only ten pigs were present. The graph indicates that the temperature increases were similar at both stocking densities, and that ten pigs took longer to reach the peak temperature at the end of loading. Randall & Patel, (1994) commented that stocking density has to be increased substantially (15 – 30%) to affect a vehicle's internal temperature.

Humidity: Graph 13 shows the effect on the humidity within the pens of having no pigs on the bottom deck of the truck compared with having 14 pigs in the pens.

The humidity changes at both stocking densities showed an initial rise as has been seen during other journeys. The rise in humidity was greater in the bottom front pen than the bottom middle pen when there were 14 pigs in both pens. This pattern had been observed in other parts of the study and deserves further investigation as it suggests that humidity changes in the bottom front pen may be compromised when compared with other pen locations; Gilkeson *et al*. (2009) noted that air in the bottom front pen 'stagnated'.

When the pens on the bottom deck were empty the humidity in both of the monitor pens rose relative to the ambient humidity. This suggests that water vapour was diffusing down from the pigs in the pens above the bottom deck, however, whether heat from the motor and catalytic converter, passing underneath the bottom deck of the stock truck, had an effect on evaporation of moisture within the effluent tank, was not investigated.

Floor area: The overseas findings, based on floor space per pig, suggest that the stocking densities used in the current study were likely to be marginal despite the apparent comfortable conditions noted on the video clips. The stocking density range available on the truck and trailer used in the current study were estimated to be between 226.4 and 244.4 kg/m^2 fitting the ranges recommended by Riches *et al*. (1996) and Ritter *et al*. (2006). When compared with the findings of those authors, it would appear that the stress levels during transport should have been positively influenced by the stocking densities used during the current study.

The driver altered stocking densities according to his perception of the impact that the ambient temperatures might have on the pigs, or if load numbers were greater or less than usual, could have impacted on stress levels. It would seem that rather than reducing stocking densities during particularly hot summer temperatures, wetting the pigs before loading might be a more practical approach for reducing heat-stress. Fox *et al.* (2014) hosed the pigs down using a simple procedure that would be practical under New Zealand conditions. However, the spraying was done when the pigs were inside the vehicle and excess water would have drained into the truck's effluent tanks adding to the overall weight of the vehicle. It would seem that hosing pigs down before they entered the vehicle would have achieved a similar result.

The effect of journey length: Whilst the literature indicates that the stress levels associated with short journeys was greater than long journeys (Gajana *et al*., 2013; Tarrant, 1989) and that such stresses have an impact on meat quality (Brown *et al*, 2012; Adzitey & Nurul, 2011), no clear definition of what constituted a short journey (whether the term related to distance travelled or time taken in-transit) was proposed.

Graphs 10 & 11 show that there was a difference in THI levels between the southbound and northbound journeys but, whilst the northbound journey was longer than the southbound journey, the topographical differences between the journeys may have been responsible for creating the greater stress levels than the journey length. Thus, travelling through urban areas or over steep or winding roads may have contributed to the findings, reported in the literature, that the short journeys were more stressful.

The effect of the number of decks that were loaded: Apart from differences in vehicle designs (especially the ventilation arrangements) used in the various studies cited, one reason for the disparity between the studies may be the use of different numbers of pigs per vehicle per load. It is likely that, because of the greater size of their pig industries, both the Australian and the transporters used in the international studies had all three or four decks fully loaded where in New Zealand only the bottom two decks were loaded with pigs. Air flows on the lower decks in the international studies would be affected by the presence of pigs on the upper decks (Gilkeson *et al.*, 2009; Norton *et al*., 2013).

The use of floor-insulating materials: Bedding materials and the use of polyester-coated flooring (Guardia *et al*., 2004) are used to either provide insulation against exposure to cold floors or to improve the comfort of the animals being transported. The provision of bedding materials and the use of non-metallic wall and floor materials have been suggested. However, none of the approaches would raise the temperatures within the pens, being focused on providing insulation against heat loss for improving the comfort of the animals. As was reported by McGlone *et al*. (2014a), bedding materials, when wet through the absorption of condensation-water and urine, could add to the pigs' discomfort.

When one considers the animal welfare problems associated with the fouling of bedding in sawdust and straw-bedded Ecobarns in New Zealand, and raised in the McGlone *et al*. (2014a) study, the temperate climate in New Zealand, plus the biosecurity risks associated with the inadvertent shedding of fouled bedding from a vehicle whilst it is travelling through farming districts (Kephart *et al*., 2014), the use of bedding materials for their insulating value in transport vehicles would appear to be unwarranted in New Zealand.

However, it would appear that the animal welfare benefits of misting or the use of water-sprinklers in stock-trucks during the summer months in New Zealand should be investigated and evaluated. Such cooling practices may require complex engineering in typical four-deck stock-trucks and might add to the overall weight of the loaded vehicles and thereby affect the economy of the road transport of stock and may not be of value for the comfort of species other than pigs.

The difference in conditions between pigs that were loaded first versus those that were loaded last

When stock trucks are loaded in New Zealand it is normal practice to fill the bottom front pen first. As a result, during a journey, transported animals will spend more time in that pen than in any other location, accentuating the risk of stress in that pen. Pigs loaded last are penned on the second deck of the trailer (where a trailer is required) and are therefore more subject to the effect of solar radiation and greater airflow when the vehicle is either stationary or when it is moving, than the pigs in the bottom front pen. The humidity in the trailer pen would be impacted by water vapour rising from the pigs in the pen below and possibly, from water vapour rising from the effluent tank.

Graphs 16 & 17 show the lag period between the data recorded for the two groups of pigs (first on versus first off) that resulted from the different times that the pigs were shut in the pens. At the end of loading the THI for the two groups of pigs (Graph 15) reached the same level suggesting that the stress levels on the pigs, associated with the loading process, were similar.

When the vehicle started moving the THI in the trailer became greater than that recorded in the bottom front pen. With the stocking densities being the same, so that body-heat from the pigs should have been equal, this would suggest that solar radiation and the presence of pigs on the deck below those on the top deck, influenced conditions on the top deck. As the vehicle continued to travel, the trailer THI diminished until there was no apparent difference between the bottom front pen and the trailer pen at the point of unloading.

Despite the pigs in the trailer pen being on the second deck, where airflows ought to have been greater, there was little difference in the humidity recorded between the two groups of pigs. This suggests that water vapour may have been trapped underneath the ceiling above the pigs on the top deck.

Overall, it was an unexpected finding that there was little difference between the conditions in the trailer pen and the bottom front pen. The author could find no references that looked at the effect of solar radiation on the top deck of transport vehicles. Several references mentioned that heat from the sun could affect animals on the top deck but there appears to be no studies that have measured the temperature effect or looked at the impact that having an insulated roof over the top deck, might have on the animals' comfort or stress levels. Whilst a roof is common on transport vehicles in the Northern Hemisphere, none of the references cited, looked at the potential insulation value of the roofing materials that were used.

Truck and trailer design

Sommavilla *et al*. (2017) and Mitchell & Kettlewell (2008) noted that the design of the stock-crates being used in their studies in Canada and Britain respectively, impacted on the welfare of the pigs being transported to such an extent that they recommended that the designs should be reviewed.

The design of stock-transport vehicles and their stock-crates will be impacted by the effect that such features as the position of the motor relative to the stock-crate, the height of the pens, the size, shape and position of their wall openings and any environmental modifications such as boarding of the wall openings, fans, sprinklers or misting will have on the environment within the stock-crate.

Apart from the use of aluminium or fibreglass wall cladding and the size, shape and position of the wall openings, stock-transport vehicles in New Zealand are very similar in design but differ from the majority of vehicles used in international stock-transport studies that have been cited. As a result, the current study was aimed at providing information that could assist the New Zealand stock-transport industry to improve the welfare of animals transported in this country.

The effect of the wall openings on ventilation: Air movement through the wall openings is created by the temperature differential between the pen and the outside of the vehicle. Since the pen temperatures were greater than the ambient temperatures, air flowed out through the openings when the vehicle was stationary. Randall & Patel (1994) indicated that the air exchange through the wall openings occurred with the ambient air flowing into the pen at the lower levels of the opening and the hotter pen-air exiting at the top of the openings. This suggests that the height of the openings could influence the humidity within the pens during stationary periods. Schwartzkopf-Genswein *et al*. (2012) noted that wall opening patterns may affect the environment within pens.

There were few references found that looked at the height and/or width of ventilation openings, with the majority of those being aimed at the ventilation of buildings; no other references could be found that looked at wall opening dimensions in stock-vehicles.

Randall & Patel (1994), supported by recommendations from the UNITED KINGDOM MINISTRY OF AGRICULTURE, FISHERIES AND FOOD (1985), recommend that wall openings on stock vehicles, that only use thermally induced air exchange, should be equivalent to 20% of the floor *area* along the total length of each side of the vehicle. Their study, based on a two-tier vehicle with pen heights of one metre, calculated that reducing the opening height by 10% or 15% of the floor *width* and having the opening the full length of the pen, led to a temperature rise in the pen of 3 and 5° C respectively; a 5% reduction in opening length (from the full length of the wall) had a negligible impact on temperatures. In their conclusion they stated that if the opening area was reduced to 10% of the floor *area*, the air temperature around the animals would rise by 5° C.

The Randall & Patel (1994) reference is confusing in that whilst they talk about 20% of the floor *area*, their model was based on 20% of the floor *width*. It would appear that this was because their model was based on having the openings the full length of the vehicle. If the recommendation of floor width was applied to the vehicle used in the current study, and assuming that the openings were the full length of the vehicle, the opening height would need to have been 485 mm.

Randall & Patel (1994) advised '*Heights less than the current recommendation of 20% of the stockable floor width should only be used with caution'*. It would seem reasonable to assume that if the length of the ventilation openings were shortened to slots, as is common practice in New Zealand, ventilation inside stock crates would be compromised. Because of the wide range of wall opening sizes and designs in New Zealand, application of Randall & Patel's (2004) recommendations would pose significant practical problems for New Zealand-designed, passively ventilated stock-crates. Their findings indicate that more studies need to be undertaken in New Zealand to evaluate the potential for improving the welfare of stock being transported, by measuring the impact that the size of the wall openings has on temperature and humidity within a stock-crate.

The effect of internal partitions on the air flows within a stock-crate: The majority of stock trucks have the internal pen-wall partitions and doors built with at least a 100 mm gap at the top of each partition and door. Those partitions, in the stock-crate used in the current study, had a 100 mm gap at the top but were otherwise of solid construction.

The gaps at the top of the partitions allow people who are unloading stock to reach through to the animals in the pen in front of the one in which they are standing so that they are able to encourage the animals to exit the pen. But the low height of the gaps increases the need for the driver to use electric goads or other prodders during unloading because the driver can only reach forwards to the length of his or her arm. Providing larger gaps could not only improve the welfare of the animals being unloaded but would reduce the overall weight of the vehicle and improve the ability of air to flow through the pens to the bottom front pen when the vehicle is moving.

Since the internal partitions have no structural purpose (Nigel Gordon, Nationwide Stockcrates, Tauranga, pers. com., 2015), it would seem that the solid section of the wall could be perforated in such a way that the risk of animals getting their legs caught, when they were moving around, could be avoided. Such an alteration would reduce the overall weight of the vehicle and thereby the economy of the vehicle and improve the ability of air to flow through the pens to the bottom front pen when the vehicle was moving.

<u>*The influence of the motor and catalytic converter*</u>: Few references (Brown *et al*., 2011) noted the possibility that heat from the vehicle's motor might contribute to heat-stress within a stock-crate despite the number of references that note that the bottom front pen in a stock-crate is the pen most prone to heat-stress problems. No references could be found that looked at evaluating the potential problem. None of the references cited, that looked at ways to modify a stock-crate's environment with fans, sprinklers or misting, commented on the impact that the modifications might have on the contribution of heat in the bottom front pen resulting from the pen's proximity to the external heat sources. It would appear that the current study is the first to address this issue.

As the abattoir had, prior to the study, identified that the majority of the pigs that had died had been transported in the front bottom pen of the truck crate, it was hypothesized that the heat from the motor may have been a major contributing factor for the higher death rates in that pen. A temperature logger that was used to measure the motor/catalytic converter temperatures was purchased after an insulation layer had been applied to the outer surface of the front wall of the stock-crate; as a result, no pre-insulation temperatures were available.

Graphs 5 and 6 show that when the vehicle's motor starts the temperature in the bottom front and top front pens rise. Conversely, data from the motor-temperature logger, collected during stationary periods showed that the temperature in the space between the cab and the stock-crate gradually declined to being close to ambient temperatures after a period of 15 to 20 minutes. These findings show that heat from a vehicle's motor *can* impact on conditions within pens in the front of a stock-crate.

CONCLUSIONS

The current study showed that temperature and humidity changes that occurred within the monitored pens were similar to the changes recorded in international studies. However, the magnitude of the changes may have been influenced by a wide range of variables such as the types of vehicles that had been used, the size of the animals that were transported and the dimensions of the pens in which the pigs were transported.

Temperature and humidity both peaked at the end of loading indicating that loading practices can have a profound effect on the ultimate stress that pigs experience during road transport. Temperature and humidity also rose during mid-journey and end-of-journey stationary periods indicating that all stationary periods can contribute to heat-stress. With the increasing requirement for such stationary periods to occur during the transport of livestock, more studies are required to determine ways to improve the welfare of the animals when loaded vehicles are stationary.

The results of the current study suggest that the designs of the stock-crates presently used in New Zealand have reached their capacity to provide adequate welfare for pigs during transport. With the expectation that species such as pigs and sheep will become larger over time, it would appear that future crate designs will need to be modified to accommodate the larger animals.

Chapter four

THE MEAT QUALITY STUDY

The effect of transport stress on meat quality

The two principal conditions that describe poor meat quality in pig meat are Pale, Soft, Exudative (PSE) and Dark, Firm, Dry (DFD) meat. PSE meat is characterised by its pale colour, soft texture, low water-holding capacity (WHC), leading to it being dry and tough when cooked. Dark Firm Dry meat is prone to spoilage and has a dark colour and firm texture that makes it unattractive to consumers and processors; both conditions are the result of pH changes that occur during processing.

It is widely accepted (Kim *et al.*, 2014; Dokmanovic *et al.*, 2014; Adzitey, 2011; van de Pere *et al.*, 2010; Hambrecht *et al.*, 2005a & b; D'Souza *et al.*, 1998) that pre-slaughter stress can have a negative impact on the quality of pig meat; with Hambrecht *et al.* (2005a) commenting that pre-slaughter stresses that occur after unloading can mask stresses created during transport.

That stressors that occur during transport can have an effect on meat quality was demonstrated by Hambrecht *et al.* (2005a & b). Faucitano (2013), in his overview, listed the pre-slaughter stressors that occurred during transport as on farm factors such as feed withdrawal, loading and handling practices, alley and ramp designs, the type of equipment used to move pigs, group sizes, trailer design and internal microclimate and the duration and distance the pigs travelled. Other authors (Dokmanovic *et al.*, 2014; van de Perre *et al.*, 2010; D'Souza *et al.*, 1998) have focused on the more immediate pre-slaughter stressors such as the off-loading procedures (including noise levels), stock handling and lairage times.

Pre-slaughter stressors: In his review of the effects of handling, transport, slaughter and chilling on meat quality, Tarrant (1989) stated that pork quality was greatly affected by pre-slaughter stressors. Andersen *et al*. (1999) noted that the degrading of meat quality may be minimised by a gentle treatment of the animals prior to slaughter and by organising the slaughter process in such a way that the carcasses are chilled quickly after slaughter.

Pigs exhibit strong hierarchical behaviours (Camerlink *et al.*, 2014; Oczak *et al.*, 2012), claiming or defending their social status by both vocal and physical aggression. Aggressive acts lead to surface wounds and/or bruising on the pig's ultimate carcass (Nannoni *et al*., 2014; Oczak *et al*., 2012; Correa *et al*., 2010) and thereby have a negative impact on meat quality. Thus, the measurement of the amount of surface wounds on a carcass can be used as a measure for the level of animal welfare that the pigs experienced prior to slaughter (Correa *et al*., 2010). In her review article, Grandin (2008), stated that psychological stressors, such as excitement and fighting, will often have a more detrimental effect on meat quality than physical stressors, such as fasting or cold weather.

On-farm factors: Multiple stressors occur during the transport of animals from the farm to the abattoir. Considerable stress can occur when pigs are being selected and moved within the farm's buildings and groups are mixed for transport, during assembly, prior to loading. Tattooing and being forced to climb a ramp to the upper decks of a truck add to the pre-transport stresses. Tarrant (1989) and Sionek & Przybylski (2016) noted that the main stressors associated with transport occur at loading and un-loading. Peterson *et al*. (2017) noted that an increase in the average loading time per pig reduced the risk of mortality during a journey. Averos *et al*. (2008), indicated that mortalities during transport could be reduced by increasing the time that it takes to load pigs for transport.

Transport factors: Heat, cold, ventilation issues, journey length and mid-journey stationary periods can all be very stressful, so that the physiological and psychological impacts of the loading stress are unable to reduce to pre-loading levels. The results of transport studies are highly variable (Grandin, 1997). Many of the studies do not include such factors as type of stock-crate used, stocking density, an animal's social rank, breed and gender, body weights or weather conditions during the journeys, all of which could impact on stress during transport. The length of the journey and stocking density, from farm to killing plant, can have an effect on ultimate pH and the incidence of PSE (Gajana *et al*., 2013).

Gajana *et al*. (2013) showed that there was a high risk for PSE occurrence when more space allowance was provided and when the animals had travelled for two hours compared with animals that had travelled for longer periods. Tarrant (1989) also reported that studies have shown that the effect of transport on meat quality was more apparent after trips of short duration rather than after long trips, he hypothesised that during long trips the physiological factors that led to the stress associated with loading had had time to dissipate.

Space allowance accounted for the largest portion of variation in total losses per trailer load in the Fitzgerald *et al*. (2009) study. The authors commented that pig weights tended to increase during the winter months leading to a relative increase in stocking density, an observation that was corroborated by Meyer (2008). They also remarked that pig numbers marketed from a farm tended to increase before the festive-season demand increased (Christmas and Easter), leading to a tendency for greater stocking densities to be transported during those peak-demand periods; this pattern has been noted by the abattoir management in New Zealand as well.

Prolonged stationary periods at killing plants often occur before the animals can be unloaded. A major stressor at the abattoir can be the length of time that the loaded truck needs to wait before disembarkation can commence (Ellis *et al*., 2008; Lenkaitis *et al*., 2007). Brown *et al*. (2007) noted that elevated core body temperatures in pigs can last for up to eight hours after transport stresses.

Since unloading at the majority of abattoirs in New Zealand is organised to occur during daylight hours, many animals are unloaded during the hottest part of the day making any stationary period, at unloading, particularly stressful.

Psychological stressors: Hamilton (2004), stated that in pigs, physical exercise and psychological or emotional stress not only trigger responses through both the voluntary and autonomic nervous systems, but also cause a pronounced metabolic acidosis. The metabolic acidosis is characterised by changes in blood parameters including increased lactic acid, decreased bicarbonate and a corresponding decrease in blood pH.

It was noted in the New Zealand pre-study abattoir report, that 82% of the deaths occurred in the lairage yards rather than the pigs being found dead on the vehicles. This suggests that transport stressors may have caused metabolic changes within the pigs during the journey that later proved fatal, after the pigs had been off-loaded. As has been previously pointed out, if conditions were severe enough to cause pigs to die, the surviving cohort animals would have also suffered from severe stressful conditions.

Questions relating to the interpretation of the levels of stress in animals, by using biological markers, were raised by Mormede *et al.* (2007). They stated that when measuring cortisol levels in pigs at exsanguination, wide variations in this stress-related marker could be due to the pulsatile nature (both diurnal and seasonal) of its production in the body, or could be influenced by feed intake, ambient temperature and humidity, age, physiological state or individual variability. Dokmanovic *et al.* (2014) confirmed the variability, when measuring cortisol levels at exsanguination, and noted that the lactate levels were also highly variable. As a result, the measurement of meat quality by using biological markers has largely been replaced by using other characteristics within the meat.

Abattoir factors that can lead to poor meat quality

The physical layout within the lairage can impact on the pre-slaughter stresses (Hambrecht *et al*., 2003; Grandin, 1980 and 1998). Ambient temperatures, slippery surfaces, sharp corners, the shape and size of the pens, poorly maintained gates and races and the attitude of the staff to the animals when moving them within the lairage, can all add to the pre-slaughter stresses.

The length of time that pigs spend in the lairage is important for ultimate meat quality (Sionek & Przybylski, 2016; Cobanovic *et al*., 2016; Hambrecht *et al*., 2005a). Sionek & Przybylski, (2016) stated that 40% of meat defects are due to the procedure in the lairage. Conditions such as the size of the pens, the number of pigs in the pens, the kind of barriers used, the type of flooring and the noise level (Goumon *et al*., 2017; Dokmanovic *et al*., 2014; Van de Perre *et al*., 2010), all contribute to the stress levels experienced by pigs held in the lairage and which subsequently impact on meat quality.

Several authors have suggested that lairage accommodation should be as comfortable as possible, not only for animal welfare reasons, but to maximise meat quality. Such practices as showering or misting of pigs has been recommended (Nanonni *et al*., 2014) to reduce body temperatures during summer months. However, Van de Perre *et al*. (2010) cautioned that the use of cold water can cause cold-stress, as indicated by pigs huddling, and suggested that shower water should be heated.

The behaviour of the staff when handling the pigs in the lairage can also impact on meat quality. Du (2016) stated that pork quality can be severely damaged during the last five minutes prior to stunning. Hemsworth *et al*. (2002) found that meat quality factors (but not pH) were highly correlated to the actions of the stockperson who moved the pigs from the lairage pen to the point of slaughter.

<u>The impact of lairage-time</u>: de Smet *et al.* (1996) found that, when compared with immediate slaughtering, holding pigs for a few hours in lairage improved meat quality. A rest period after transport, allows the lactic acid in the muscle tissue that has accumulated as the result of the stress of transport to subside. The optimum length of time for pigs to be rested in the lairage pens before slaughter is at least two hours (Faucitano 2013; Hambrecht *et al.*, 2005a & b; Hamilton *et al.*, 2004; Grandin 1998), with short lairage being up to 45 minutes and long lairage being greater than three hours. Brown *et al*. (1999) found that pigs that spent six hours in the lairage, with access to food and water, allowed most of the physiological parameters to return to pre-transport levels.

Dokmanovic *et al.* (2014) found that variability in lairage times had a profound effect on meat quality. Lairage times affect the ability of pigs to calm down after the novelty and stressors of transport, with individual animals taking variable times for their metabolic processes to stabilise. However, Van de Perre *et al*. (2010) commented that whilst they could not find a significant effect of lairage time, any improvement in meat quality related to resting in the lairage may have been lost due to the pre-stunning stresses.

Overview of the measurement of meat pH and its relationship to transport stress

Apart from its impact on consumer acceptance, measurement of meat quality has several important aspects. Poor meat quality can be an indicator for poor animal welfare conditions pre-slaughter (Belk *et* *al*., 2002), it can impact on the shelf-life of the meat (Faucitano *et al*., 2010), it can reduce the ability of meat to hold a cure and thereby affect the processing of carcasses (Cisneros *et al*., 1996) and it can affect the water-holding capacity (WHC) of the meat leading to the economic impact of drip loss (Du , 2016; den Hertog-Meischke *et al*., 1997).

Factors that are involved in pork quality include pH, colour, tenderness, water-holding capacity and chemical composition. All of those factors can be influenced by breed and heredity as well as processes involved in breeding, slaughtering, meat processing and storage (Kim *et al*., 2016). Kim *et al*., (2016) stated that meat quality can be described by the sum of all meat quality characteristics, which are typically adjusted by the effects of muscle pH.

The pH changes occurring in a carcass during the first 24 hours after exsanguination are important for the quality of the final meat or meat products. Protein denaturation will occur if pH falls to too low a level, or if a relatively low pH sets in at a time after slaughter, when the carcass temperature is still high (Andersen *et al*., 1999). Where carcass lactic acid levels are high (pH ≤ 5) the muscle tissue would appear pale, would be soft and have excess moisture leading to 'drip loss', a condition called PSE meat (van de Perre *et al.*, 2010; D'Souza *et al.*, 1998). Conversely, where the lactic acid levels are low (pH ≥ 6.8) the resulting carcass meat would be dark, firm and dry (DFD) (Adzitey & Nurul 2011; Guardia *et al.*, 2005). Both PSE and DFD meat create problems for processors and are unacceptable to consumers.

The pH of muscle tissue is important to meat science since the pH at specific times during the conversion of muscle to meat, as well as the ultimate pH of meat, affects many quality factors (Hambrecht *et al*., 2003; Dutson, 1983). In international practice the evaluation of pork quality is based on very different parameters and criteria. The most popular parameters that enable the evaluation of defective meat include pH, meat colour, WHC, electrical conductivity, tensile strength and a range of metabolic markers (Tomovic *et al*., 2014). Tomovic *et al*. (2014) also stated '*Characteristics should be easily measurable, which means that a destructive cutting of a carcass must not occur. Therefore, the easily accessible M. semimembranosus and M. longissimus dorsi are recommended as representative muscles*.' These factors are influenced by multiple interacting factors including breed, genetics, feeding, pre-slaughter treatment and stunning, slaughter method, chilling and storage conditions.

Maki-Petays *et al*. (1991) state that, on the killing line, only direct puncture measurements using portable pH meters are useful where large numbers of pH measurements in rapid sequence are required. However, the skill and experience of the technician are very important in determining the accuracy and precision of the measurements (Dutson, 1983). Dutson (1983) and Andersen *et al*. (1999), also suggested that there is a problem of variance in pH among different areas of a muscle and different types of muscle, and that comparisons cannot necessarily be made between pH data that have been collected by different measurement techniques.

The effect of pH on meat quality

<u>The physiological changes that occur when muscle is converted to meat</u>: Changes in meat pH result from the enzymatic breakdown of glycogen (glycolysis), in the anaerobic muscles of a carcass, with the conversion of the glycogen to lactic acid. In the live pig, homeostatic mechanisms maintain muscle pH at between 7.0 and 7.2. After slaughter, pork with normal colour and WHC reaches an ultimate pH of 5.7 to 6.1 at 24 hours post-slaughter and 6.3 to 6.7 at 45 minutes post-sticking (Kim *et al*., 2016).

Physiologically, calcium ions are used by the body to activate the myofibrils in muscle cells (Bowker *et al*., 2017). [For schematics of muscle structure see den Hertog-Meischke *et al*., 1997]. The calcium ions are transported into the muscle cells through ryanodine channels (Basic *et al*., 1997; Fujii *et al*., 1991) leading to the contractions of the myofibrils. den Hartog-Meischke *et al*. (1997) noted that it is generally accepted that most of the water in the muscle cell is present in the myofibrils, and that only a small fraction (0.5 g/g protein) is chemically bound to the charged groups of the muscle proteins (myosin and actin).

Post-slaughter, the muscle cells (sarcomeres) collapse and less water is held within the cell membrane and by the muscle proteins. As the carcass cools more water is lost from the muscle cells leading to increased loss of water from the carcass (drip loss).

Myosin and actin are the major contractile proteins associated with muscles, with myosin binding to actin during muscle contraction. When myosin is denatured (as in the conversion of muscle to meat) the bond does not occur leading to relaxation of the muscles and a soft texture. Since both actin and myosin bind water, when they are denatured the WHC of the muscles is decreased. Barbut *et al*. 2008 and Du (2016) stated that in extreme cases weight loss ('drip-loss') could reach as high as 10%.

For comparative purposes, internationally, pH measurements that are taken as an indicator for meat quality, are commonly taken at 45 minutes (pH_{45}) and at 24 hours (pH_{24}) after a pig has been killed; pH_{24} is often referred to, by some authors, as the ultimate pH (pH_u). Kim *et al*. (2016) suggest that the initial pH, the ultimate pH and the temperatures post-mortem are important factors in determining the meat quality of pork.

The decline in pH is primarily affected by the amount of glycogen in the muscles at the time of slaughter. In addition to the extent of pH decline, the rate of decline in early post-mortem muscle is a very important determining factor of fresh pork quality (Lonergan, 2012). The rate of pH fall contributes to a range of meat quality characteristics including changes in colour, WHC and shelf-life (Barbut *et al*., 2008). Consumers have shown a preference for pork that had a pH_{45} of between pH 6.3 and pH 6.7 (Kim *et al*., 2016).

<u>*Pale Soft Exudative meat*</u>: This condition is known to occur in pork, beef and poultry. The mechanisms by which the condition occurs in the latter two species are not identical to that of pigs, so the condition is often referred to as PSE-like meat in those species. PSE is triggered by acute stress prior to slaughter (Kim *et al*., 2014) so that poor animal welfare is often correlated with the incidence of PSE.

When the initial pH falls very rapidly, and the carcass temperature is still high, PSE is most likely to occur. The combination of high temperature and relatively low pH accelerates glycolysis and the denaturing of muscle proteins. The rapid drop in pH can be triggered by genetics and pre-slaughter stresses such as transport stress and adverse lairage conditions.

Physiologically, under PSE conditions, twice the amount of calcium ions can be released post-mortem, which causes excessive glycolysis and the buildup of lactic acid (Basic *et al*., 1997). As D'Souza *et al.* (1998) pointed out, there is a gradual decline in muscle pH post-slaughter under normal circumstances but, in pigs acutely stressed prior to slaughter, the rate at which muscle pH declines is accelerated.

<u>*Dark Firm Dry meat*</u>: DFD meat results from the depletion of glycogen in the pig before slaughter (Newton & Gill, 1981). The carcass meat is darker and drier than normal and has a firmer texture. As a result of handling, transport and pre-slaughter stresses, the muscle glycogen may be used up before

slaughter, leading to little lactic acid production in the meat at slaughter. Such meat is characterised by a high (greater than pH 6.0) pH_{24} and deficiencies in glucose and glycolytic intermediates.

DFD meat can result in accelerated bacterial spoilage. Spoilage becomes apparent when bacteria begin to utilise the amino acids in the meat (Newton & Gill, 1981). Under aerobic conditions bacteria exhaust the glucose at the meat surface. Since glucose levels are very low in DFD meat, amino acids are utilised more rapidly than normal leading to spoilage occurring more rapidly than in normal meat.

***Rationale for the meat quality phase of the study*:**

Chefs, in New Zealand, have frequently remarked that they find the quality of pig meat produced in New Zealand is very variable. Since meat quality has been reported to be affected by transport conditions it was hypothesised that the location of pigs within a stock-crate could be one of the factors that impact on that variability. It was thought that pigs being transported in the most stressful locations, such as the bottom front pen of a stock-crate, may have poorer meat quality than those pigs that were transported in less stressful locations. To evaluate this, the current study looked at the difference in meat quality between pigs that were transported in the bottom-front pen (the first to be loaded) and pens in the rear-most pen on the upper deck of the trailer (the last to be loaded).

In the literature cited, transport stress was assessed by many authors with reference to the THI levels that were recorded during journeys. However, as d'Ambrosio Alfano *et al*. (2011) point out, THI levels are a somewhat arbitrary measurement and indicate a potentially stressful environment but do not measure the direct effect on individual pigs. Thus, it was felt that different levels of stress during transport might be able to be measured by differences in the levels of meat quality.

At the beginning of the study it had been hypothesised that if pen conditions during transport, had been severe enough for a pig or pigs to have died, cohort animals would have been severely stressed as well, leading to stressed pigs at slaughter. As a means to measure the direct effect of transport stress on pigs it was anticipated that the impact of the stress during transport might be able to be evaluated by measuring any meat quality differences between two groups of pigs, one group in a high stress and the other in a low stress location. Since the bottom front pen had been identified in the literature as the location where the greatest number of dead pigs had been found that pen, into which pigs were loaded first, was proposed as being the high stress location.

The pre-study mortality report from the abattoir had shown that transport-related deaths in the pens on the top deck of a truck or trailer were rare and that deaths amongst pigs transported in a trailer were lower than amongst the pigs that had been transported in the trucks' stock-crate. It was considered that that, plus the perceived better air flows in the top pens, indicated that stress levels in the top pens of the trailer should be better than in the pens on the lower deck. Studies had shown that when a vehicle was moving, air flowed over the back wall and moved forwards against the direction of the movement of the vehicle. That suggested that the least stressful pen ought to be the top pen at the back of the trailer, the pen that was loaded last.

As a result of the above considerations it was decided to contrast the meat quality of pigs that were loaded first against those that were loaded last.

A 'low transport-stress' model: A farmer, situated equidistant from the southbound farm on the Canterbury plains, designed a transport protocol aimed to minimise the stress associated with the transport of his pigs to the abattoir that was used in the current study. He marketed 100 pigs per week and sold his carcasses to butchers as being from minimal-stress pigs; he had all of his carcasses pH tested at 45 minutes from slaughter to validate his claim.

On his farm the pigs that were close to a marketable weight were held in any one of three pens in one of the sheds on the farm. On the day before sending his pigs to the abattoir he raddled those pigs that were at the appropriate weight for marketing and stopped adding feed to the individual dry-feed hoppers in the pens late in the afternoon; it was anticipated that there would be no feed in the hoppers after mid-night.

At 5.00 am the next morning, he quietly separated the raddled pigs from their groups and slowly walked them to a set of elevated holding pens outside the shed; the height of the pens was set to the height of the lower deck of the transport truck. The truck (without a trailer), of similar design to the truck used in the current study, arrived at 6 am and the pigs were loaded onto the two lower decks using a large board to assist pushing the pigs into the vehicle; no electrified goads, slapping or yelling was permitted.

The route chosen for delivery of the pigs to the abattoir involved travelling up one steep (12% slope) incline and through two small townships. The farmer had several years previously found that the alternative route, that whilst flat, involved the truck travelling through one large and five small townships, caused lower pH readings in his carcasses. The pigs arrived at the abattoir at 8.00 am and were killed after a minimum of 60 minutes rest in the lairage.

***The meat quality study*:**

<u>*The study protocol*</u>: The study protocol was designed to replicate normal pig transport procedures from a farm to an abattoir. Seven southbound trips were monitored to evaluate the difference in meat quality between the fourteen pigs that were loaded first versus the fifteen that were loaded last.

Apart from the tattooing at the abattoir, the monitor pigs received no more stressors than were normal for pigs arriving at an abattoir, being held in lairage pens and then being moved to the stunning pen. In the current study, apart from a mid-journey stationary period of 15 to 30 minutes, transport stressors were minimised with weather patterns being the most significant variable.

After observing the pigs that were being loaded for the southbound journey, the author travelled to the abattoir to record the time of arrival of the pigs, the length of time taken to unload the monitor pens and the time the pigs spent in the lairage before being presented for slaughter.

As the monitor pigs entered their lairage pens they were tattooed with a cypher that denoted to which group they belonged (first on versus first off). It was arranged that as far as was commercially possible the pigs in both the monitor pens spent the same amount of time resting in the lairage. Timings of the loading, stationary periods, unloading, lairage procedures and the time from sticking to pH measurements being taken were recorded. THI measurements were calculated from the records taken by the data loggers attached to the back wall of the bottom front pen and the front wall of the last pen to be loaded on the trailer.

<u>*Unloading*</u>: The southbound pigs arrived at the abattoir during the late morning or in the early afternoon. The actual length of time of unloading depended on the arrival time of the truck and whether other vehicles were being unloaded when the truck arrived at the abattoir. When delays occurred the loaded stock truck was parked, without shelter from the sun or wind, on the side of the road that led into the abattoir.

Once the stock truck was backed up to the unloading ramp, the ramp was raised to the level of the upper deck and unloading of the trailer commenced. The first pen of pigs on the trailer ('first off') was unloaded as an independent group and the pigs were moved to a smaller lairage pen where they were tattooed with a numerical cypher using a slap tattoo. With the exception of the pigs in the bottom front pen ('last off'), the remaining pigs on the truck were unloaded as a mixed group, were assembled in a holding yard at the end of the unloading ramp and were then moved to lairage pens. The pigs in the bottom front pen were moved as an independent group to a pen of the same size as the first group of pigs and tattooed with a distinguishing cypher. The driver occasionally used an electrified goad to speed the process of unloading.

Lairage: Lairage pens at the abattoir varied in size and the yardman drafted the pigs off from the holding pen according to the number of pigs required for the size of lairage pens available; there were always pigs from other farms present in the lairage when the trial pigs were being unloaded.

To ensure that the time spent in the lairage for the two groups of pigs (first on versus first off) was as close as possible, the two groups were killed in sequence, with a larger group of pigs being killed between them to balance the difference between the timing of the two groups of pigs arriving in the lairage pens. This resulted in a difference, from week to week, between the times the trial pigs spent in the lairage.

pH measurement: At the beginning of the slaughter process the 14 or 15 monitor pigs were moved from their pen in the lairage to a holding pen just outside the 'stunning pen' where they were to be electrically stunned and then bled out. Once the pigs were in the holding pen, groups of five pigs were pushed into the 'stunning pen' with a great deal of shouting and slapping with an inflated plastic bag on the end of a pole. Each group of five pigs took three to five minutes to slaughter, so that each monitor group took up to 15 minutes before the next group from the lairage pens was ready to be killed.

After stunning, each pig was suspended from a rail where it was bled out and then held for a variable period for blood to be drained from the neck incision. Once a sufficient period for exsanguination to have been completed had elapsed, the pigs were mounted on a drum that rotated them through a scalding trough before they were passed into a chamber where their hair was beaten and then singed off. Following the de-hairing process the carcasses were passed through another chamber where they were washed and 'polished' by rotating brushes.

After leaving the polisher the carcasses were moved past a series of butchers and meat inspectors at a rate of 100 carcasses per hour. The time from sticking to reaching the grader, who was positioned immediately in front of the chiller rooms, was close to 50 minutes so that pH measurements, carcasses being identified by the tattoo on the rump, were taken just before the group of pigs reached the grader. After being graded for weight and back-fat they were finally moved to the different chilling rooms.

After the butchers had dressed the carcasses meat inspectors examined each carcass and shifted any defective bodies to a side-chain ('detain rail') where a butcher trimmed away any defects as required. Trimming was only commenced when a sufficient number of carcasses had accumulated on the detain rail to warrant a butcher being seconded from the chain to the detain rail. Since this period was variable, care was taken to ensure that as far as possible the pH measurements of all of the trial carcasses were taken as close to 45 minutes post-sticking as possible. Pigs from the detain rail were added to the main rail randomly after their trimming was completed.

The pH measurements were made using a spear-meter probe (Eutech Instruments; IPEU – PH Spear, 34634/40). As the author was not familiar with the use of the pH probe, to ensure the accuracy of the measurement the floor manager was used to calibrate the probe and take the measurements. The floor manager routinely monitored pH for farmer clients and was therefore experienced with both the equipment and the technique.

After checking the calibration of the probe, the probe was inserted into the semimembranosus muscle through the 'bung hole' (the perianal opening through which the anus and rectum had been removed) and held in the muscle until a stable reading was recorded. The probe was then cleaned after each measurement was taken.

During the meat quality phase of the study visual observations of wounds and bruising on the carcasses, as described by Correa *et al*. (2010), were recorded in the chillers. At the end of the study pH records from the 'low stress' farm were accessed and compared with results from the pig carcasses produced by both the southbound and northbound farms.

RESULTS

The following data was collected during the study of the impact of transport stress on meat quality.

Table 11: Ambient temperature and THI values for six southbound journeys to the abattoir

		1st off		Last off	
	No.	Mean	Range	Mean	Range
THI	6	66	52 - 74	64	49 - 78

		Highest T.	Lowest T.	
	No.	Mean	Mean	Range
Ambient temperature °C	6	19.70	11.20	8.3 - 21.25

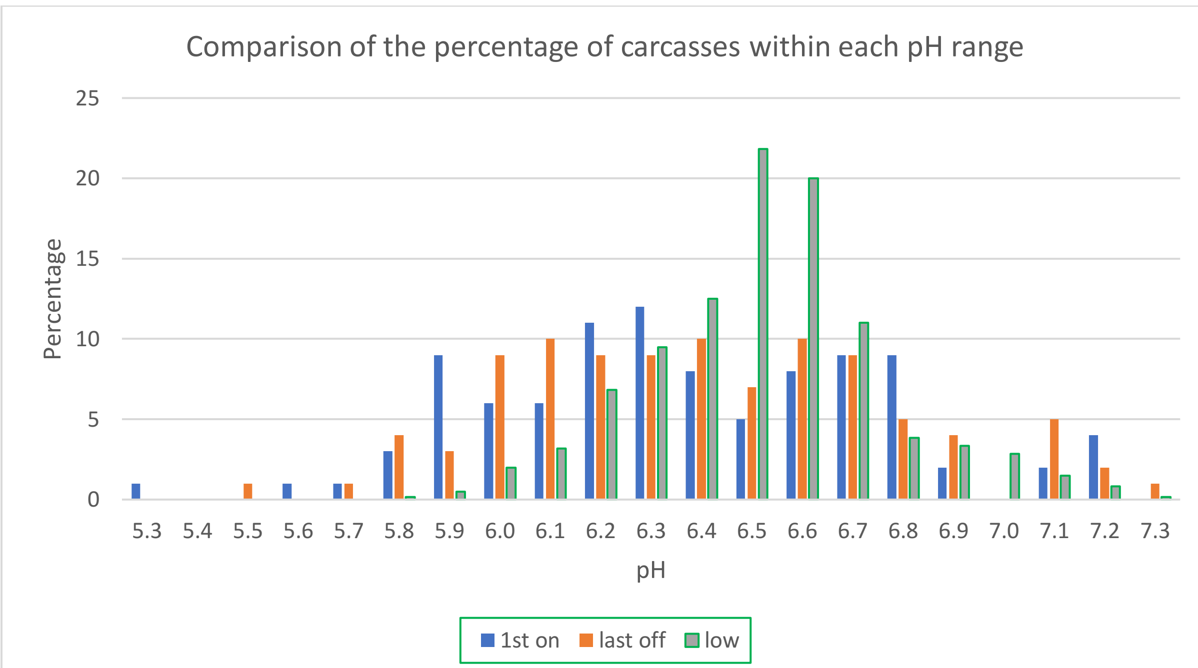
Table 12: Temperature differences between the bottom front pen and the trailer pen during journeys to the abattoir

	No.	1st off	Mean High °C	Mean Low °C	Last off	Mean High °C	Mean Low °C	Amb. °C	Mean High °C	Mean Low °C
Mid-journey Stationary	6	17.3 - 25.9	22.1	20.0	18.4 - 23.9	21.5	20.2			
Mid-journey Moving	6	16.6 - 26.3	22.2	19.3	18.2 - 24.1	21.5	19.8			
Unloading	6	15.4 - 26.3	21.3	18.8	17.6 - 23.0	22.3	19.5	11.6 - 21.7	18.7	14.0

Where: Mid-journey stat. = the mid-journey stationary period Mid-journey move = the period between the mid-journey stationary period and arrival at the abattoir

Table 13: Waiting times at the abattoir

	No.	First off Minutes	Mean	Last off Minutes	Mean	Minutes range	Mean
Truck wait time	7					5 - 17	10
Lairage wait time	7	14 - 138	77	28 - 112	88		
Stun to pH reading	7	35 -40	37	30 - 67	40		



Graph 18: pH records comparing pigs in the bottom front pen with those in the trailer pen and from the 'low-stress' farm

Table 14: Percentage of pigs within selected pH ranges

pH range	First off	Last off	Low stress farm
5.5 < 6.2	21.2	21.8	12.1
6.3 < 6.7	25.3	22.4	76.2
6.8 < 7.2	4.1	5.3	11.8

Table 15: **Percentage of pigs with bite marks or scratches**

	Bites			Scratches		
	0	1 to 2	3+	0	1 to 2	3+
Southbound	26	2	0	26	36	36
Northbound	8	20	24	8	34	20
Low stress	11	22	23	11	12.5	33

DISCUSSION

Measurement of the meat quality of the pigs transported in the 'high stress' versus the 'low stress' pens

Preliminary considerations: A logger holder was not welded onto the wall of the top-rear trailer pen until the meat quality phase of the study was about to be started. As a result, the assumption that the upper-rear pen would be less stressful than the bottom front pen had not been validated at the commencement of the meat quality study.

The top pen: The top and sides of the upper deck have a greater exposure to ambient conditions than the lower decks. The pre-study report from the abattoir used in the current study showed that 35% of the deaths reported over the three-year period, occurred in the bottom front pen and that deaths of pigs transported on the top deck of either the truck or trailer were rare. It was assumed that better airflows over the pens on the top decks of the truck and trailer would reduce the water vapour concentration and thereby decrease the impact of the any heat-stress created by the higher temperatures on the top deck that were caused by exposure to the sun.

Prior to the current study being undertaken Figure 9 in the Norton *et al*. (2013) paper, based on predicted air flows, was considered. The paper indicated that the rear pen in the upper deck of a passively ventilated vehicle would be hotter than the front pen of the bottom deck. However, because in their study the bottom deck analysis was based on a mechanically ventilated system and air can move from the lower decks to the upper decks, a direct comparison of the degree to which the temperature differences between the two decks could not be made.

On the basis of the perceived optimal air flows that were thought to occur over the back wall of the trailer unit, it was decided that the least stressful pen ought to be the rear pen on the upper deck of the trailer.

The bottom deck: Studies by Nannoni *et al*. (2014) and Brown *et al*. (2011 & 2007) identified the bottom front pen as being more stressful than other pen locations, and that pen location impacted on the level of stress that pigs experience during transport, however, much of the work was conducted in pot-belly trailers that are not used in New Zealand.

Both Gilkeson *et al*. (2009) and Norton *et al*. (2013) predicted that the bottom front pen would be the hottest area during transport, a finding confirmed by field studies (Brown *et al*., 2011 & 2007). Thus, whilst the bottom pen could be taken as a high stress environment, the comparative level of stress in the top-rear pen of the trailer appeared to be equivocal.

Randall & Patel, (1994) noted that doubling the deck height of the lower decks decreased the temperature by 0.5° C for aluminium-clad vehicles. It was considered that the lower ceilings in the vehicle used in the current study would not have reduced the dissipation of accumulated water vapour when compared with the higher ceilings used in the literature study. Thus, the impact of the difference between the pen heights in the Norton *et al*. (2013) study and in the vehicle used in the current study should have meant that the conditions on the lower deck in the current study should have been more stressful.

<u>*The trailer pen*</u>: Despite the moderate ambient temperatures that were recorded, temperature levels (Tables 11 & 12) suggest that heat-stress conditions may have occurred during five of the six journeys that were monitored, with the highest temperature levels being recorded in the trailer pen. This observation, supported by the study by Fiore *et al*. (2009), was not able to be quantified by statistical analysis because of the small number of observations and the number of variables involved. Considering the animal welfare, and potential meat quality implications, further examination of the issue would appear warranted.

The trailer was loaded last and the temperatures recorded were slower to peak during loading than in the bottom front pen and were quicker to cool once the truck started to move. This resulted in the bottom front pen recording higher THI levels than the trailer pen at loading; the reverse process occurred during unloading. After the meat quality study was started it was found that even in the cooler months of autumn, THI readings of greater than 70 in the trailer pen occurred with the same frequency as those recorded in the bottom front pen.

Fiore *et al*. (2009) revealed that there were more variations in the temperatures recorded on the top decks of vehicles than the bottom decks, with stationary periods being a prime contributor. The top pens, in the current study, would have been affected by heat from the sun conducted through the aluminium floor above them, and through the walls of the crate, plus heat from the pigs below them. However, unlike the bottom front pen, air-flows created by air entering the wall openings in the top-rear pen, could be expected to cool the pigs when the vehicle was moving, as was indicated by the calculations of Gilkeson *et al*. (2009), when they looked at conditions within small trailers. As a result, as was demonstrated in the data that was collected during the current study, the primary periods when high temperatures were recorded in the rear-back pen were when the vehicle was stationary.

The short length of the waiting period at the abattoir, with the moderate ambient temperatures, would have given little time for the pigs in the top-rear pen to have been affected by heat from the sun during the unloading period.

<u>*The impact of stationary periods prior to unloading at the abattoir*</u>: Sutherland *et al*. (2009a) noted that prolonged waiting times prior to unloading can have a significant effect on meat quality. Sionek & Przybylski (2016) stated '*Loading and unloading are the most stressful elements in pig transport that affects meat quality*'.

No shelter or protection from the weather was provided at the abattoir for waiting stock-trucks. As has been shown in this study and supported by the study of Lenkaitis *et al*. (2007), stationary periods, particularly those that occur during the maximum heat of the day (Heat map 1), lead to an increase in the temperature and resulting THI levels within the pens. Similar problems exist for vehicles loaded with stock waiting at wharves to board the inter-island ferries (Fisher *et al.*, 2004; John Tacon, stock-truck driver training consultant, pers. com., 2015).

Prior to the meat quality phase of the study it was noted that stationary periods, when a load of pigs arrived at the abattoir, were often of greater than one hour's duration. Whilst scheduling by the abattoir staff was aimed at ensuring that minimal delays in the arrival of loads of pigs occur, problems at a farm or traffic conditions occasionally led to two or more vehicles arriving at the same time to be unloaded. As a result, a driver may have had to wait for an hour, or more, before the unloading of the vehicle could proceed. Since this often occurred in the middle of the day, the ambient temperature in summer may cause considerable heat-stress for the waiting pigs (Fiore *et al*., 2009; Lenkaitis *et al*., 2007).

The impact of the mid-journey stationary period: During the mid-journey stationary period the temperature (and resulting THI) of the trailer pen was often greater than that of the bottom front pen (Table 10); temperatures in both pens increasing over time during the stationary period. Despite that, over the full length of the journeys, the average temperature in the trailer was 1.5^{o} C less than in the bottom front pen.

On the single southbound journey where the driver did not have a mid-journey stop it was noted that the THI levels at the end of the loading period, gradually declined until the end of the journey. It is therefore possible that the effect of the high temperatures recorded during the mid-journey stationary periods could have diminished by the time that the trailer was unloaded and thereby negated any negative effect on meat quality.

As Fiore *et al*. (2009) noted, mid-journey stationary periods during the central hours of the day may increase the overall stress of transport and thereby have a negative impact on meat quality. Since the mid-journey stationary periods during short journeys (up to eight hours) are not essential, it would have been useful to have monitored the meat quality after more journeys where that stationary period had been avoided. It was not possible, in the current study, to determine what the impact of any increase in transport stress associated with the mid-journey stationary period had on the quality of the meat, however it would appear possible that if mid-journey stationary periods are prolonged, as is now required in Europe and North America, the stops may have an impact on ultimate meat quality.

The impact of unloading at the abattoir: During the meat quality phase of the study the vehicle did not have to park up and wait for another vehicle to unload. The waiting times recorded (Table 11), were taken from the time that the truck arrived at the abattoir, before backing up to the unloading ramp, to the beginning of unloading. During that period, whilst ambient temperatures rose by 4 to 5^{o} C, temperatures in the monitor pens did not rise to the same extent. The temperatures in the pen that was unloaded last (the bottom front pen) were greater than those that were unloaded first suggesting that those pigs could have experienced a greater heat-stress as a result of the length of the unloading process.

Once the truck had backed up to the off-loading ramp at the abattoir, the major stressor for the pigs was the way in which the driver unloaded the pigs. Because the fixed wall at the front of each pen only had a 100 mm gap at the top, the driver was restricted from reaching through to encourage pigs out through the open door on the right-hand side of the pen in front of him. As a result, he used a wand to poke at pigs as they milled around in the pen in front of him causing considerable stress for the pigs as evidenced by their increased vocalisations.

Compared with the loading process, the unloading appeared considerably more stressful as the pigs did not appear to want to leave the vehicle and needed robust encouragement. Combined with the potentially greater psychological stress that the last pigs would have suffered during the unloading, it appears likely that there may have been an impact on the quality of their meat as a result of the unloading process (Correa *et al*., 2010; Ritter *et al*., 2006; Anderson *et al*., 2002).

When the pigs exited the truck, they moved down the unloading ramp, which had a maximum decline of less than twenty degrees, with little evidence of baulking or slipping, even when the ramp was damp. Pigs from the two monitor pens were not mixed with other pigs and showed little evidence of distress when moved to their lairage pens. However, apart from the two monitor pens, pigs from different pens were mixed together in the marshalling pen at the end of the ramp, aggressive interactions and increased vocalisations occurred until groups were moved off to their respective lairage pens.

<u>The impact of lairage-time</u>: Sionek & Przybylski (2016) state that 40% of meat defects are the result of conditions within the lairage. They noted that the geometry, stock densities and noise within the lairage area were major contributors to stress amongst pigs and led to pH changes within the meat.

The lairage pens at the abattoir were covered by a roof and had wind cloth across one of the walls. This protection prevented the pigs from exposure to sunburn, rain or snow but had little effect on any wind. As a result, pigs tended to huddle together on very cold days indicating that they were undergoing cold-stress (Hoff, 2006).

The configuration of the lairage at the abattoir meant that there were few small pens suitable for holding the small groups of the 14 and 15 trial pigs (the larger group being in the trailer pen). The most suitable pens were at either end of the lairage meaning that one group would have to walk further to the stunning pen than the other. The distance between the two pens was approximately 50 meters and the vigour with which the yardman moved the pigs meant that one group would receive more physical and psychological stress immediately before slaughter than the other.

Throughout this phase of the study lairage times varied widely (Table 11). Lines of pigs from other farms, which were already in the lairage when the trial pigs arrived, needed to be processed before the trial pigs could be dealt with. Interruptions for meal breaks also led to a variation in the time that the trial pigs spent in the lairage. Since it was not possible to ensure that the two groups of pigs (first on versus first off) remained in the lairage for the same length of time, pH readings could have been influenced by the variable lairage times.

Several studies suggest that the time spent in the lairage has an effect on meat quality (Adzitey, 2011; Averos *et al*., 2007; Becerril-Herrera *et al*., 2007). Whilst the short length of time that the trial pigs spent in the lairage was unlikely to have contributed to DFD meat, it may have contributed to the low pH readings recorded in the study.

<u>The holding pen adjacent to the stunning pen</u>: Robust encouragement was needed to move the trial pigs from their lairage pens to the holding pen next to the stunning pen. By the time the pigs reached the holding pen they were very vocal and showed extreme anxiety. It is also possible that the proximity to the noises and smell from the inside of the building, contributed to the pigs in that pen being agitated; issues suggested by points raised by Lewis *et al*. (2010) and Grandin, (1997). As a result, when the door to the stunning pen opened and groups of five pigs were encouraged to go through, the pigs baulked and needed a great deal of noise and slapping to get then to leave the holding pen. Weschenfelder *et al*. (2013) noted that lactic acid levels could rise very quickly so that the high level of stress that was created when the pigs were moved into the stunning pen could have led to meat quality defects.

<u>The pre-slaughter stress levels</u>: When considering the stresses that occurred during the transport of the southbound pigs, it would appear that they should have, with the possible exception of the mid-journey stationary period, had a low-stress journey. The type of housing that they were finished in, the low-stress loading procedures, the moderate ambient temperatures and the short interval from arrival at the abattoir to being penned in the lairage should all have contributed to the pigs experiencing minimal stress during the journey, points raised by Goumon & Faucitano, (2017), Guardia *et al*. (2004) and Grandin, (1998).

However, procedures in the lairage including the variable time that the pigs were given to relax in the lairage, with rest periods of greater than 2 hours only occurring on two days, could have contributed to the incidence of the low pH meat. This lack of rest-time and the highly stressful procedures involved in the movement of the pigs from their lairage pens to the stunning pen, suggest that lairage procedures may have had a significant impact on the pH recorded at the abattoir.

pH measurements taken during the study

Variability in the timing of the carcasses reaching the point at which the pH measurements were to be taken: Some difficulties were experienced in the timing that pH measurements were taken. A series of interruptions to the flow of the trial pigs occurred because of the way in which carcasses entered the section of the chain where the pH measurements were to be taken.

The rate at which pigs were processed (the chain speed) was set at 100 pigs per hour. This meant that without delays the trial group of 14/15 pigs should have been able to have been monitored within nine minutes from the time that they left the de-hairing table. However, delays meant that from the first carcass to be pH monitored, to the last in the group, the timing varied and was up to 20 minutes (Table 13).

A major delay occasionally occurred after the carcasses were examined by the meat inspectors. Some of the trial pigs had minor defects that required trimming on the detain rail. Trimming was only conducted when a sufficient number of carcasses had accumulated on the detain rail. Since entry to the detain rail only occurred sporadically, the length of time that a carcass rejoined the 'dressing chain' was very variable. The processing delays were of a random nature so that the time that it took to pH-monitor each group of trial pigs varied from group-to-group.

Internationally, meat quality, as measured by pH, is taken at fixed points in time with the first measurement usually being taken at 45 minutes (pH_{45}). Depending on the rate at which the carcasses cooled the timing of the pH_{45} reading can be crucial to the interpretation of the meat's quality. The variable timing that occurred during the current trial was discussed with Professor Patrick Morel (Meat Scientist, Massey University) who indicated that variations of up to five minutes, whilst not ideal, were unlikely to have a significant impact on the interpretation of meat quality.

Analysis of the meat quality data: The abattoir used in the current study routinely tested pH levels for a number of their suppliers who promoted the quality of their product by its purported superior meat quality. Since the staff were conversant with the use of the pH probe and the methods of cleaning it and standardising its recordings, the author used them to take the readings under the author's direct supervision (Dutson, 1983). Despite that, on one occasion the staff member failed to standardise the probe leading to the set of data being invalid.

The optimum pH range for good meat quality is between pH 6.3 and pH 6.7 (Kim *et al*., 2014 & 2016; Dutson, 1983). Whilst not supported by statistical analysis due to the small sample size and the number of variables associated with the data set, some trends appear to have occurred. In the trial group (first on/first off) 43% had pH levels below 6.3, with no apparent difference being seen between the two groups, and 47.7% were in the optimum pH range, again with no obvious difference between those pigs that were the first to be loaded versus those that were the last to be loaded. Four pigs in the trial group were recorded as having pH levels below 5.7 and as a result could be expected to have had PSE meat (Kim *et al*., 2016).

It would appear from the literature references that the small number of pigs with pH levels greater than 6.7 could have been due to the pigs not having had experienced chronic stress as might have occurred if they had been kept in the lairage pens for a long period. The high level of low pH readings suggests that the pigs had been suffering from acute stress. Whilst no concrete conclusion can be drawn from the data, it would appear that any meat quality difference between the two trial groups would have been minimal suggesting that there may have been little difference in the accumulated pre-slaughter stresses experienced by the two groups of pigs.

Because the abattoir management were reluctant to permit further monitoring due to the impact that the study was having on stock movements in the lairage and on the processing floor, it was decided to discontinue further data collection.

Comparison between the results from the 'low-transport-stress' farm and the trial pigs: In contrast to the data from the trial pigs, the data from the 'low-transport-stress' farm, appeared to show a lower incidence of pH readings below pH 6.3 (12% compared with 43%) and a higher incidence of pigs in the optimum pH range (76.2% compared with 47.7%). The majority of the readings from the 'low-transport-stress' farm that were in the high pH range (11.8%) were reported to have occurred on the one day when the pigs had been held in the lairage overnight (a wait of approximately 24 hours in the lairage). Cobanovic *et al.* (2016) indicated that such prolonged lairage periods could contribute to the incidence of high pH readings. Whilst these figures were not supported by statistical analysis, they would suggest that there may have been a difference between the results from the two farms.

The data that was collected for the low-transport-stress farm had been accumulated during the summer months, when ambient temperatures were higher than were recorded during the trial study. A number of factors could have contributed to the low-transport-stress farm having had more pigs in the optimum pH range than were found in pigs from the trial farm. The loading procedures at the farm commenced very early in the mornings, whilst involving the mixing of pigs from different pens and holding the pigs in the elevated loading pens, was aimed at minimising the loading stresses (Camerlink *et al.*, 2014). The journey that involved only travelling through two townships on the way to the abattoir, avoided the stresses of repeated stopping and starting that are inherent in travelling through urban areas. The longest period of uninterrupted travel (80% of the journey) occurred immediately after loading. Graphs 10 & 11 show that prolonged uninterrupted periods during journeys, even those involving travelling through urban areas, can lead to a reduction in the THI levels created by the loading process.

Finally, the time of day that the pigs arrived at the abattoir (9 am), would have meant that the pigs would have travelled and been held in the lairage, during the coolest part of the day. The time that the low-transport-stress pigs spent in the lairage was not recorded however it was reported that the times were always greater than one hour because pigs that had been held overnight had to be processed before them.

Since the same staff at the abattoir would have used the same methods for moving the pigs from their lairage pens to the stunning pen, it would suggest that the robust methods for moving the pigs may have had a minimal impact on the final pH readings. However, evidence from the literature suggests that such stressful procedures should have had an impact on the pH levels recorded.

Records of carcass damage: Adzitey (2011) and Correa *et al.* (2010) noted that animals can suffer from bruises and injuries during loading and unloading onto vehicles that can result in carcass damage and thereby poor meat quality. The loading of pigs from the southbound and low-transport-stress farms was observed to determine the level of aggression and riding-behaviour that occurred prior to loading. On both farms there was minimal aggression or riding-behaviour. However, when carcasses from both farms were checked in the chillers using the criteria outlined by Correa *et al.* (2010), few of the bodies were free of bruises or wounds (Table 15).

When comparing the carcasses from the two farms used in the study there appeared to be more bite marks on the northbound pigs than the southbound pigs whilst the percentage of scratch wounds were similar. Since bite wounds are more commonly associated with hierarchical aggression and scratches are more associated with riding behaviour (Correa *et al*., 2010), the findings appear to suggest that hierarchical aggression during the loading of the pigs at the northbound farm may have caused the greater percentage of pigs with bite injuries when compared with the pigs from the southbound farm. The incidence of scratches on the southbound carcasses appears to have been the result of riding behaviour of the pigs when they were in the lairage.

Aggressive acts lead to the production of adrenaline, which in turn leads to the production of lactic acid in the muscles. As a result, the presence of wounds and bruises can be used to indicate the potential for poor animal welfare (Correa *et al*., 2010). It would therefore appear that lairage procedures at the abattoir may have contributed to sub-optimal carcass quality.

The impact of the time of the year when the study was undertaken: The meat quality phase of the study was undertaken from April to June when cooler weather prevailed. That season has an effect on meat quality has been pointed out by a number of authors (Cobanovic *et al*., 2016; Gajana *et al*., 2013; van de Perre *et al*., 2010; Fitzgerald *et al*., 2009; Haley *et al*., 2008a). These authors indicated that PSE meat (low pH readings) was less common in the summer months than autumn or winter with Cobanovic *et al*. (2016) suggesting that adverse weather conditions in winter lead to chronic depletion of glycogen stores.

However, transport studies in the Northern Hemisphere are impacted by the severity of the winter conditions. Averos *et al*. (2007 & 2008), showed that transport in Europe during the winter months is more stressful for pigs than in the summer months and Fiore *et al*. (2009) noted that temperatures below 5° C in Europe are five times more common than temperatures above 30° C. Macara *et al*. (2016) reported that on the Canterbury plains there were on average 40 days/year when the temperature was greater than 30° C and 41 days/year when the temperature was below 0° C. The highest temperature recorded in Canterbury was 42.4° C and the lowest was -11.6° C. However, the Macara *et al*. (2016) report included data from alpine areas in Canterbury where cold conditions could be expected to be more extreme than on the plains.

Several authors (McGlone *et al*., 2014b; Goumon *et al*., 2013; Grandin, 2002) have commented that frostbite was a significant cause of animal welfare and meat quality problems in the Northern Hemisphere; such conditions have not been reported in New Zealand (Grant Badger, Senior Meat Inspector, AsureQuality, 2017). Gajana *et al*. (2013) noted that the incidence of PSE meat was greatest in Autumn and lowest in Spring showing that time of the year can have an effect on meat quality. It would therefore appear that meat quality effects reported in the Northern Hemisphere studies would be different to those found in New Zealand.

CONCLUSIONS

The purpose of the meat quality phase of the current study was an attempt to provide a qualitative measurement of the effect of transport stress under New Zealand conditions, rather than relying on the questionable value of using THI levels. However, the problems associated with identifying a specific low-stress pen in a stock-crate contributed to a result suggesting there was no difference in the meat quality of the pigs in the two groups that were chosen for comparison.

Comparison of meat quality studies that were conducted in the Northern Hemisphere with studies conducted in New Zealand, should be undertaken with care. A wide range of transportation and climatic variables, variation in unloading procedures and variation in lairage conditions can occur between such studies, such that the results obtained from one region may not be applicable to another region.

Chapter five

INSTALLATION OF INSULATION AND THE FAN

Introduction

Dead on arrival and DIY pigs, resulting from heat-stress during transport, are reported to be primarily the result of the build-up of the temperature and humidity that occurs during periods when the vehicle is stationary. The multiple stressors on animals that occur during the period that a vehicle is being loaded, lead to a substantial rise in both temperature and humidity which dissipate slowly once the vehicle starts moving. Pen conditions at the end of loading, or immediately before unloading commences, are the most stressful for livestock during road transport (Xiong *et al*., 2015; McGlone *et al*., 2014a). Sutherland *et al*. (2009a) found that the percentage of DOA pigs increased as waiting times at the processing plant increased, with the highest losses occurring at waiting times of over four hours.

During mid-journey stationary periods and when the vehicle is being unloaded, the temperature and humidity also rise, often to critical levels. Evidence from the current study and supported by international transport studies, show that the bottom front pen is the pen here the greatest heat and humidity accumulates during these stationary periods. Gilkeson *et al*. (2009), also noted that air in the bottom front pen stagnates in passively ventilated vehicles. It would therefore appear that improvements could be made to the welfare of livestock if the conditions within the bottom front pen could be improved.

Rationale for the use of fans in the current study

The purpose of fans is to remove moisture from around the animals and thereby increase evaporative cooling (Kettlewell *et al*., 2001a; Fuquay, 1981). The author considered that, since the primary ventilation concern was the buildup of heat and humidity in the front pens, if air could be blown into those pens from the front wall and encouraged to move laterally to increase the air flow through the wall openings, a better environment in the front pens could be achieved. It was also thought that if the air in the front pens moved more quickly out through the adjacent wall openings, air from the middle and rear pens might be encouraged to move forwards creating a more turbulent air flow within the decks, providing greater comfort for the pigs.

The conclusion reached by the author, from the literature cited, was that any additional inflow or outflow of air created by positive pressure ventilation systems, should be primarily aimed at modifying the environment in the front pens. Whilst previous authors (Kettlewell *et al*, 2001a) advised that any fan systems used should be designed to extract air from the pens and blow it to the outside of the vehicle, this would lead to the body of the fan being inside the pen; the author considered that blowing air into the front pens should be investigated.

Ventilation systems used in livestock transport vehicles

In New Zealand, the majority of stock trucks are ventilated passively. Passive ventilation works on the principle that once the vehicle begins moving, the air flowing along the sides of the stock-crate draws air out from the pens, refreshing the air in the pen environment and reducing both the temperature and humidity within the pens. In passively ventilated transport vehicles, when the loaded vehicle stops for more than a few minutes the temperature and humidity rise, primarily from the heat and water vapour produced by the livestock, unless environmental factors such as wind or rain impact on the conditions within the pens. These factors make the stationary periods that occur during loading, mid-journey stops and at unloading, critical points for reducing compromised animal welfare during transport in passively ventilated vehicles.

Air scoops: Creating an 'air scoop' by drilling holes in the head-board, as an alternative approach to using fans for the cooling of the bottom front pen, was considered by Mitchell & Kettlewell (2008). However, they noted that holes, when drilled through the 'head-board', reduced the ventilation in the stock-crate. Such air scoops could not be controlled so that cold air would enter the front pen or pens during winter adding to potential cold-stress problems.

Discussion with a stock-crate manufacturer (Nigel Gordon, Nationwide Stockcrates Limited, 2015) ascertained that 'air scoops' had been used in New Zealand in the past. A variety of these devices were designed that worked on the principle that air could be scooped from an opening at the top of the front of the stock-crate and vented into the front pens. However, the devices lost favour when it was found that animals could become excessively chilled and avoided standing or lying in front of the vents, it was also found that many of the designs led to large amounts of rainwater filling the effluent tanks.

Mechanical ventilation systems: In the Northern Hemisphere, many regulatory authorities have required mechanically operated ventilation systems to be installed in stock-transport vehicles. Mechanically operated positive pressure ventilation designs, as described in the literature, required the ability to close off wall openings to direct the flow of fan-generated air movement from the back of the vehicle to the front pens.

All of the fan systems described in the available literature (Norton *et al*., 2013; Mitchell & Kettlewell, 2008; Warris *et al*. 2006; Kettlewell *et al*., 2001a), involved having the body of the fan inside a pen. Whilst this would be practical where the height of the ceiling in the pen allowed the fan to be out of reach of the pigs, the low ceilings in New Zealand stock trucks would mean such systems would have to withstand interference from the pigs. Even the smallest fans are quite bulky and could have led to pigs becoming injured. Even those fans that were designed to be attached to the side-wall of the stock-crate, protruded into the pens (Kettlewell *et al*., 2001a).

It was revealed by Norton *et al*. (2013) that when a truck was moving, in either passively or actively ventilated vehicles, air flowing from the back of the vehicle to the front was being progressively obstructed by pen partitions, the bodies of the stock being transported and the loss of air through the wall openings (when boarding was not being used). Added to that is the problem that any air reaching the front pens would have accumulated additional temperature, humidity and pollutants from the animals that it passed as it moved forwards (Norton *et al*., 2013).

As a result, there would be significant differences in the environments within different pens (Brown *et al*., 2011) with the front pens being hotter in passively ventilated vehicles than the back pens (Weschenfelder *et al*., 2013; Ellis *et al*., 2008) and cooler in the rear pens in actively ventilated vehicles where the fans had been installed in the rear of the vehicles. Thus, the mechanically ventilated systems described in the literature, though improving conditions within stock-crates, can create ventilation problems and do not appear to fully meet the requirements of the EU regulations.

The design of the fan-assisted ventilation system used in the study

Physical considerations: The author assembled a group to help design a fan system that would be both practical and able to be added to the stock truck that was being used in the study. The group consisted of a ventilation consultant (Matt Darnbrough, NZDuct+Flex, Christchurch), an automotive electrical engineer (Tony Reid, Specialist Auto Electric Limited, Christchurch) and the manager of the transport company who owned the stock-truck used in the study (Murray Writon, Ellesmere Transport Limited, Dunsandel).

The following parameters were considered important by the author:

- The design had to be able to be attached to conventional New Zealand-style stock-trucks
- The fan and ducting were to be attached between the truck's cab and the front wall of the stock-crate without interfering with the movement of the cab when the truck's motor was being serviced
- Air was to be drawn from above the cab of the truck to avoid any exhaust fumes being blown into the front pens
- The system would need to be able to operate under all weather conditions, particularly when heavy rain occurred
- The system would need to be fully automated but would need to be able to be inactivated for over-night stoppages or times when there were no animals on board
- Air flows were to be only started when the vehicle became stationary for periods longer than stoppages that occur during normal traffic conditions
- The power supply would need to be able to run the fan for periods of up to four hours (the projected length of time that a stock-truck would be stationary during a ferry crossing of Cook Strait)
- Vents were to open into the three lower front pens of a four-deck stock-crate with air flow rates being equal in all three pens
- Vent openings were to be designed to avoid injuries or interference from the pigs in the pens
- Air flow rates were to be such that they would not disturb any animals in the pens or create undue chilling or additional heat inside the pens

Insulation of the front wall of the stock-crate: Early in the current study it was found that heat from the truck's motor and catalytic converter affected the front pens of the stock-crate. In an attempt to reduce the impact that that heat had on the front pens, it was proposed that the front wall should be insulated. A number of options were considered with the priority being that the insulation material should be of a thickness that allowed a ducting system to be installed in the gap between the cab and the front wall of the stock-crate.

As a result, a 19 mm layer of foam sheet (Armaflex, Forman Industrial Supplies, Christchurch) with an R value of 0.54 was chosen as it could be easily applied to the stock-crate. Whilst thicker foam sheets were available, with greater insulation value, the diameter of the ducting was unknown at that time, so a conservative approach was taken (Figures 5 and 6).

Later in the study, a bracket was put in place in the gap between the cab and the stock-crate so that a temperature logger could be mounted. The height and position at which the logger was mounted was at the same level and position as the logger situated on the inside front wall of the bottom front pen. It was anticipated that the impact of the insulation could therefore be measured.

The ducting system: Because the cab of the truck needed to be folded forwards when the motor was being serviced, the ducting was fixed to the front wall of the stock-crate. The vehicle used in the study had a sufficient gap to allow for the installation of ducting of up to 180 mm diameter.

To ensure that air-flows in each of the pens was the same, the ducting was constructed in tapered sections. The sections were able to slide over each other and were provided with a clamp so that the height of each section could be adjusted as required. A drain-hole was provided at the lowest point of the ducting so that any water that entered through the fan assembly, could drain away, thereby avoiding water draining into the effluent tank.

90 mm outlets were cut into each of the bottom three front pens of the front wall of the truck (Figure 20) and fitted so that there was a minimum of protrusions into the pens that might cause injury to the pigs.

The fan: The consultants determined that to provide an airflow of 50 kph in each of the pens, the fan would need to be able to deliver air at 1200 m^3/hour. As a result, a 318 mm diameter, 12 volt, Maradyne (44-M123K) reversible fan, with an air flow range of 1150 – 1750 m^3/hour, was attached to the top of the vertical ducting by a 90 degree ‘elbow’ section of ducting. The fan used was originally designed to be a motor vehicle radiator fan and as such was able to accommodate operating under wet conditions.

To minimise the amount of water that might enter the ducting through the fan, and to reduce the problems created by ‘air scoops’, with cold air being vented into the pens when the vehicle was moving, the fan was set to face at right angles to the direction of the vehicle’s travel.

The electrical system for the fan: A 12-volt, deep cycle, dry cell battery (Century C12-120DA), was used to power the fan. A sensor was set to recognise the voltage drop when the truck’s motor was started causing the truck’s 24-volt battery to be charged. The fan’s electrical system was then set so that the fan would switch on three minutes after the truck’s battery was no longer being charged. The voltage drop or lack of charging, then switched the fan on after the delay of three minutes, ensuring that air flowed into the front pens during all stationary periods but avoided problems of short stops that would occur at controlled intersections.

When the truck’s motor was running, the fan’s dry cell battery was being charged. An isolator switch was installed so that the fan could be switched off manually when the vehicle was parked up at night or when no animals were being carried.

To extend the length of time that the battery could operate the fan, the controller was set to run the fan on a cycle of ten minutes on and three minutes off; the length of the cycles could be adjusted as necessary. The total operating time for the fan was approximately four hours. Additional wiring was included for an on/off warning light to be installed in the cab that would alert the driver that the fan was operating, and further wiring was installed for a monitor that could be used by an auditor to be able to determine that the fan had been switched on during journeys.

Figure 20: **The fan, ducting and wall insulation**

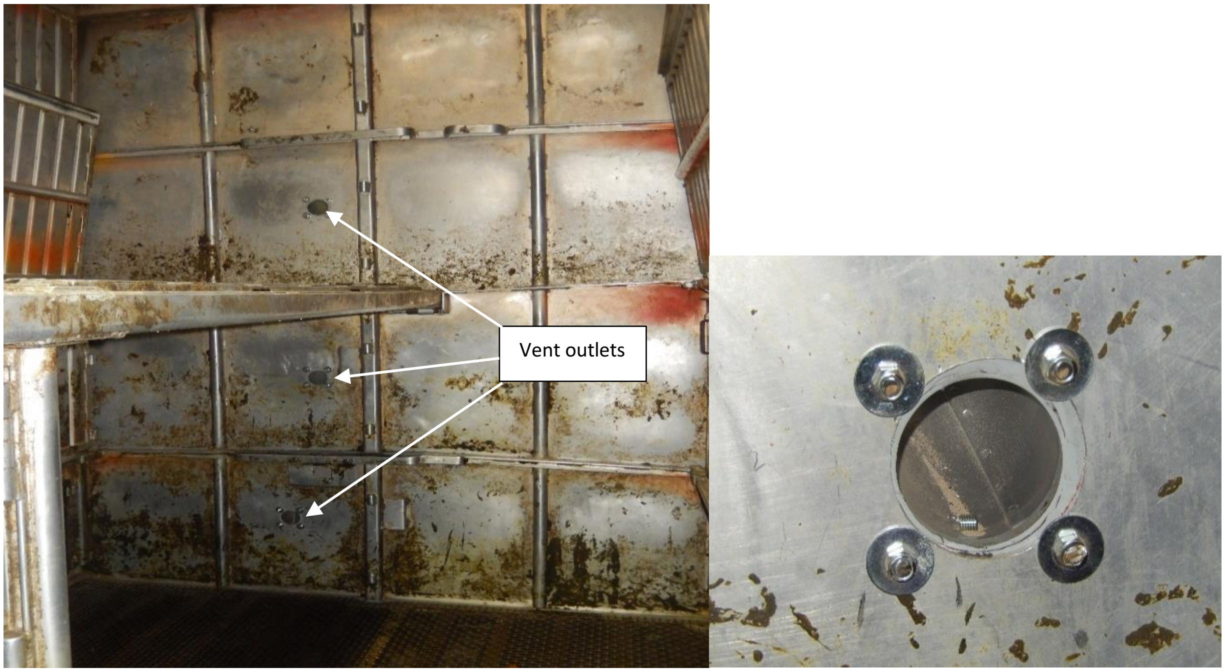
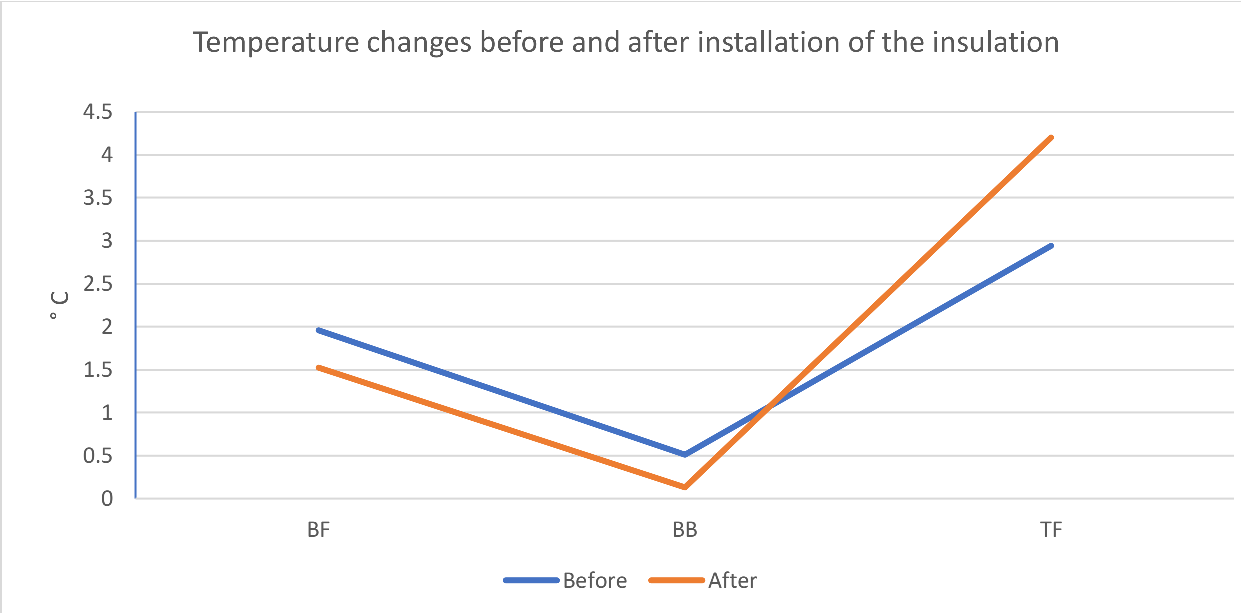


Figure 21: **Position of the air outlets in the front wall of the stock-crate**

RESULTS

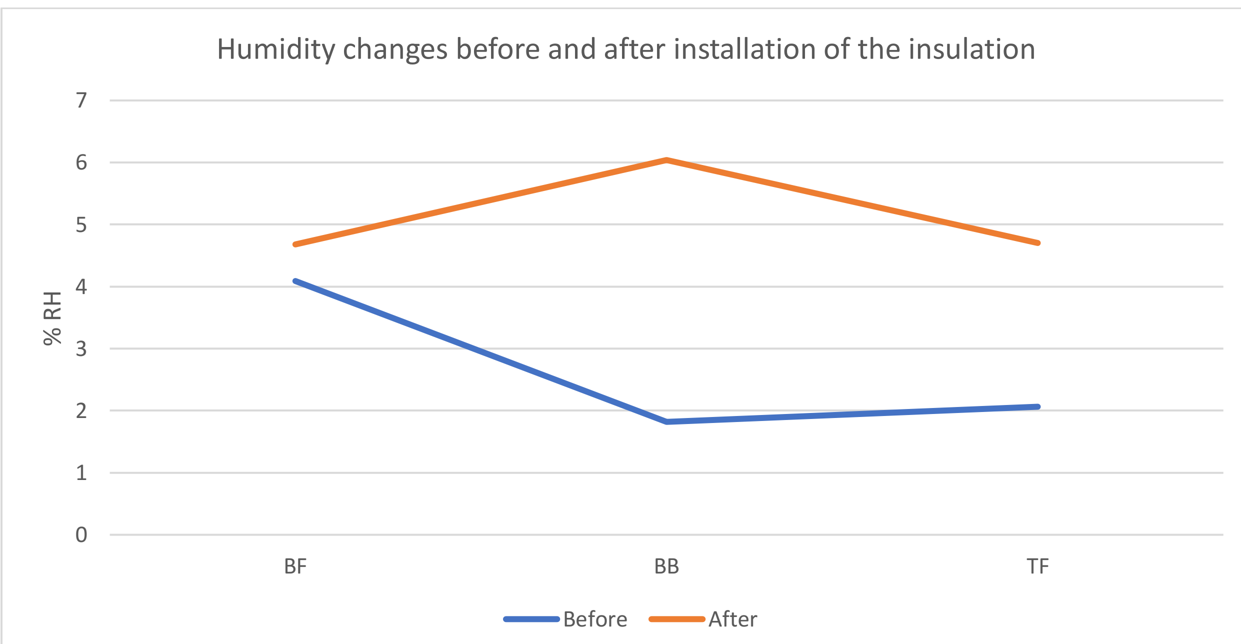
The temperature logger, that was mounted in the gap between the cab and the front wall of the stock-crate, was not in place before the insulation material was installed. As a result the effect of the insulation material was compared with conditions withn the front pens of the stock-crate and the ambient temperatures recorded beside the driver's window.

Data from the beginning of loading to the end of fifteen journeys were examined for the periods before and after the insulation had been installed. The average temperature difference between the ambient temperature and temperatures recorded on the front and back walls of the bottom front pen, and the top front pen at the beginning and end of journeys were then calculated.



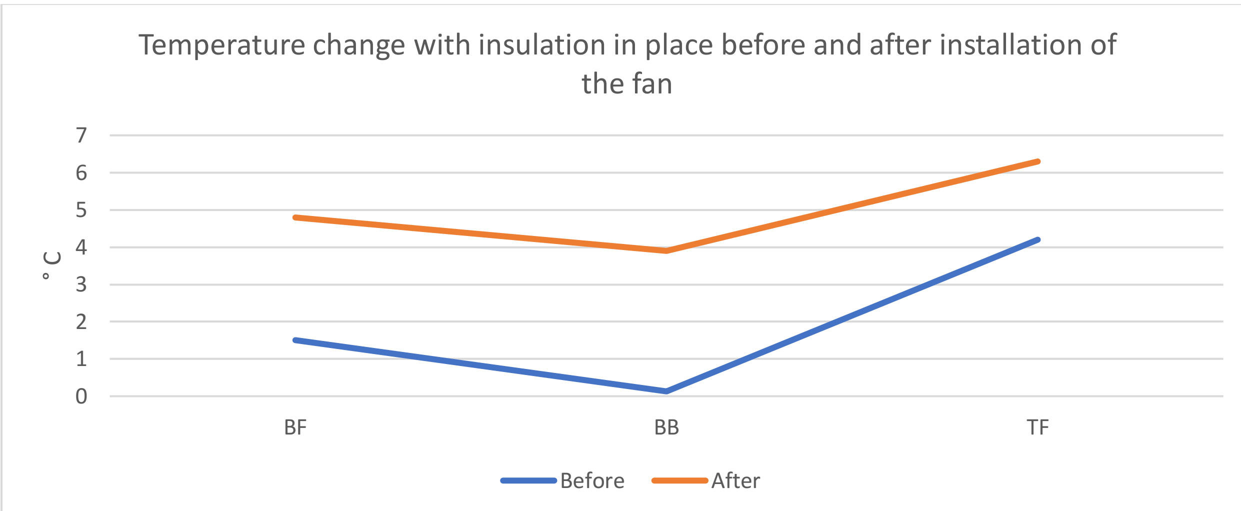
Where: BF = the temperature rise on the front wall in the bottom front pen BB = the temperature rise on the front wall of the bottom middle pen TF = the temperature rise on the front wall in the top front pen between the start and end of loading

Graph 19: Temperature changes before and after installation of the insulation

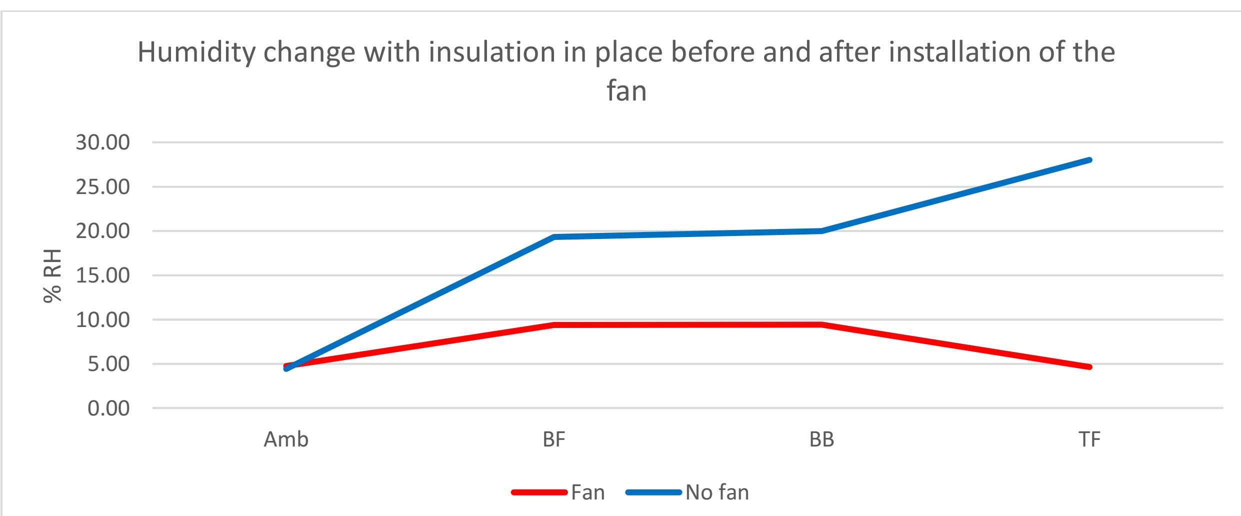


Graph 20: Humidity changes before and after the installation of the insulation

Data from 15 journeys were compared for the periods after the insulation had been installed and before the fan had been installed, with the period after the fan had been installed. The average temperature difference between the ambient temperature and temperatures recorded on the front and back walls of the bottom front pen, and the top front pen at the beginning and end of journeys were then calculated.

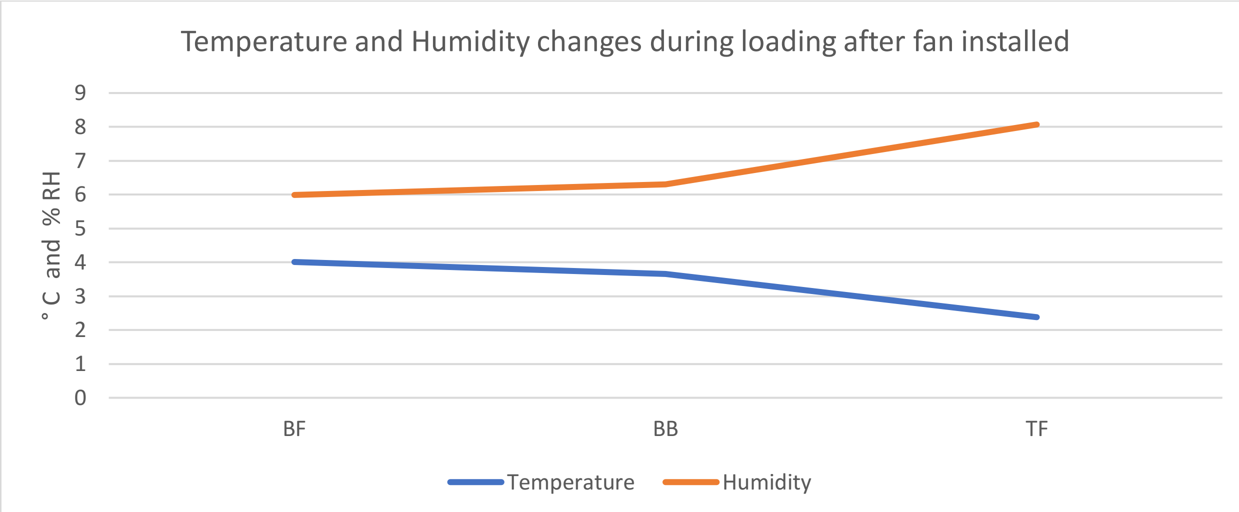


Graph 21: Temperatures recorded after installation of the insulation and after the installation of the fan



Graph 22: Humidity recorded after installation of the insulation and after the installation of the fan

The temperature and humidity changes that occurred during loading over fifteen journeys, were calculated for the period after the fan had been installed.



Graph 23: The effect of the fan on the temperatures and humidity in the bottom front, bottom middle and top front pens during loading over fifteen journeys

Table 16: Comparison of average THI values in the bottom front pen before and after installation of the fan from start to the end of loading

																Av.
Before	56	57	59	60	61	61	65	65	67	70	72	73	74	74	78	**66**
After	52	57	57	57	57	60	60	62	62	64	64	69	70	72	79	**63**

DISCUSSION

Rationale for the use of a fan

Physical principles: Whilst pigs have a limited capacity to use cutaneous evaporative cooling to maintain homeostasis under high ambient temperatures, their ability is further limited when the air surrounding them has a high water vapour content. As was suggested by the studies of Huynh *et al*. (2007), and Armstrong (1994), it was thought that the beneficial effect of a fan or fans would be driven, in part, by a reduction of the water vapour surrounding the animals rather than any effect that the fans would have on the temperature within the pen.

Evaporation of water depends on temperature, air pressure, humidity and air speed (Hammond and Goslin, 1933). When temperature increases a higher molecular motion results in expansion of volume and a decrease of density. Thus, the amount of water vapour in the air influences its density (Engineeringtoolbox.com).

The speed at which air flows over a surface affects the rate at which water evaporates, with the air movement dispersing the water particles that were in the air, thereby reducing the humidity. The greater the body surface exposed to the air the greater the effect of the air movement (Sciencing.com). This helps explain (in part) why pigs prefer to lie down during road transport since when standing the proximity of other pigs would create a space between their bodies where air movement was restricted. It would therefore be expected that standing pigs, in the confined air space of a pen, would feel hotter than if they were lying down.

Since the air pressure around a transport vehicle would be relatively constant it would appear that an important feature of fans is to create a turbulence in the pens' air, or create an increased air-flow that would break the water vapour barrier on the pig's skin allowing for increased evaporative cooling.

When temperatures are high, as was shown to occur towards the end of loading, and air movement is limited, the air would absorb more water vapour until it becomes saturated. As the water vapour content in the air increases the air loses its ability to absorb more water vapour, reducing the capacity for evaporative cooling and increasing the sensation of heat-stress.

If the water vapour content in air stays the same and the temperature drops, the relative humidity increases. Conversely, if the water vapour content in air stays the same and the temperature rises, the relative humidity decreases because colder air doesn't require as much moisture to become saturated (Sciencing.com). Therefore, when the fan introduces ambient air into the pens, the temperature within the pen could be expected to drop and the humidity to rise. However, the ambient air would have a lower water vapour content than the air in the pen thereby having a net effect of reducing the humidity in the pen. Thus, the combination of adding cooler air and increasing the ability of the air to absorb more evaporative-moisture from the pigs, plus the increased airflow, would lead to a reduction in the level of heat-stress experienced by the pigs.

The above principles indicate that under high humidity conditions air movement that leads to a reduction in humidity, will have a greater effect on heat-stress conditions than reducing the environmental temperature.

In the current study it was proposed that by blowing air into the front pens and forcing air out through the adjacent wall openings the desired effect could be achieved without the need for introducing any fans within the pens or the need to close-off any of the wall openings.

Examination of the studies that used fans: The mechanically operated positive pressure ventilation systems described in the literature were either designed to pump air into the pens or extract air from the pens with the body of the fans being inside the stock-crate. Because of the confined space in the pens in New Zealand-designed stock-crates, particularly the low ceiling space available, it was considered that any equipment, such as a fan, would be likely to cause injuries, or could be interfered with by the animals.

None of the positive pressure systems described in the literature appeared to be appropriate for the current study. Apart from the problem of the New Zealand-style pens having limited space, the positive pressure systems described in the literature required the majority of the wall openings to be closed off at all times when the fans were operating. This meant that either the wall openings would need to be closed off during the summer months or the fans were not to be used and passive ventilation would be required during hot weather. Providing adequate ventilation when the wall openings were closed during very hot weather in the summer months, would appear to be very challenging.

The use of boarding appears to be primarily driven by the need to protect animals from the extreme cold of the winters in the Northern Hemisphere. The temperate climate of New Zealand means that such severe cold does not occur in winter (Macara, 2016) making a requirement for boarding seem unnecessary. In New Zealand boarding would pose major problems for transport operators. Apart from the cost and the need for major design changes to the physical structure of the vehicles, the added weight of boarding would affect the economy of the road transport of livestock.

Another issue that was considered was the design of the vehicles used for the overseas fan-trials. The vehicles were not articulated as is the norm in New Zealand, but had a single, un-articulated deck. Whilst it would appear to be practical to have a fan situated in both the truck and trailer units in New Zealand, the need to abut the truck and trailer units when the vehicle was being loaded and unloaded would create problems for the installation of a fan unit at the front of the trailer. As the majority of the deaths reported in the pre-study abattoir report were in the bottom pens of the truck unit, and fewer deaths had been reported in the trailer unit, it was felt that the focus for the current study should be on the truck unit.

All of the studies cited, that trialed positive pressure ventilation systems, operated the fans continuously from the beginning of a journey to the end of the journey. It would appear that this was due to the wall openings being closed throughout the journeys thereby restricting ventilation even when the vehicle was moving. As was demonstrated in the current study, heat-stress conditions were rare when the vehicle was moving. Therefore, the need for having fans operating when the vehicle was moving, and the wall openings were not closed off, appeared unnecessary.

There was also the problem that the continuous use of the fans for long journeys would require considerable battery power. It was calculated by the electrical engineer that even with pulsed use, a 12-volt battery would only provide enough power for a single fan for a little over four hours; providing more or larger batteries or using the truck's batteries would create significant problems for New Zealand-designed vehicles.

Kettlewell *et al*. (2001a) had stated '*in employing active ventilation it must be recognised that extracting air from the container is preferable to trying to blow air into the container. This removes the possibility of air jets that in close proximity to animals can be detrimental to their welfare.'* Whilst Grandin (2002), commented that pigs will baulk at air blowing on their faces. These comments were noted but it was considered that the Kettlewell *et al*. (2001a) statement was made in recognition of the impact that blowing air into a stock-crate during sub-zero temperatures in winter would create severe cold-stress problems. With respect to the comment from Temple Grandin, it was felt that during transport air would be entering the pens through the wall openings creating a draught so that pigs, during transport, would always be exposed to some degree of draught. Provided that the additional air input from the fan was not excessive, it was felt that the pigs' welfare would not be compromised as was confirmed in the videos taken when the fan was operating.

As previously stated, heat-stress during road transport is primarily driven by the stresses created during loading. The adverse environmental conditions created at the end of loading gradually dissipate as journeys progress, with rises only occurring during stationary periods. It was therefore considered that if the level of heat-stress that occurs during loading could be reduced, the impact would have a positive impact on the welfare of the animals throughout the journey.

The fan trial protocol

The protocol for the fan-system designed for the current study, was prepared to ensure that the system would be able to be used on as many different types of vehicle used in New Zealand, and under all climatic conditions. Whilst there are a number of different makes and models of vehicle being used for the transport of livestock in New Zealand, the majority are of a COE design and have a gap between the cab and the stock-crate. It was considered that whilst the width of the gap would vary between stock-trucks, the objective of the study was to determine whether the principle of blowing air into the front pens could improve the welfare of the pigs in those pens without disturbing the pigs in the pen.

Weather protection: The system needed to be as weather-proof as possible. The driver had indicated that when heavy rain occurred and where there were no facilities available to drain the effluent tanks, effluent occasionally overflowed from the underfloor effluent tanks and covered the floor of the bottom pens creating a welfare and hygiene problem for the animals being transported. It was therefore considered that any additional risk of increasing the amount of water that entered the effluent tanks should be avoided. The ventilation engineer advised that a hole drilled at the bottom of the ducting would not have a significant effect on the efficiency of the system but to avoid the rusting of the edges of the hole a plastic grommet should be inserted to protect the edges.

The cowling containing the fan was to be positioned at right angles to the direction of the truck's movement so that a minimum amount of water would enter the ducting when the vehicle was being driven in the rain. The angled position of the cowling would also reduce the risk of the system acting as an 'air-scoop' that could result in the chilling of the animals nearest to the internal vents during travel in cold weather.

Positioning the fan-opening inside the air space behind the truck's wind shield was considered. However, it was thought that heat from the truck's motor might increase the temperature in that space making the air warmer than the ambient air and that some of the truck's exhaust gases might have accumulated in that space. However, it was considered that the inclusion of exhaust fumes into the airflow, when the opening was outside the wind shield air space, was unlikely because the fan would only operate when the truck's motor had been switched off.

The power supply: A major concern related to the power supply for the fan. It was considered that if the fan was powered from the truck's 24-volt battery during prolonged stationary periods, the fan might draw off so much power that the truck's battery might not have enough power to re-start the truck's motor at the end of a prolonged stationary period. As a result, it was considered necessary to have an independent power supply for the fan.

It was also considered important that the driver should not have to operate the fan beyond switching the system on at the start of a day and switching it off when there was to be no stock on board for prolonged periods. Ultimately, it was envisioned that the system should be able to be operated without any input from the driver and should be able to be checked by an auditor who would want to ensure that the system had been operating.

To conserve the independent battery's power, and to ensure that the fan only operated during stationary periods, a control system was necessary. The electrical engineer was required to design a control system through which the fan speed and on/off pulsing could be adjusted; he was also required to ensure that the battery could operate the fan for a minimum of four hours. The electrical engineer determined that to meet the operating time limit, the fan needed to operate for ten minutes and then be switched off for three minutes when the vehicle was stationary; the sequence would be adjustable as necessary.

Provision was made for a light to be installed on the dashboard inside the cab that would indicate to the driver whether the fan was on or off. However, because of the cost and the uncertainty regarding the success of the study, the light was not installed.

The fan control unit: The electrical consultant had offered the following ways by which the fan could be operated automatically:

1. Using GPS to start the fans when the vehicle was stationary for more than 3 minutes
2. Using a sensor on the driveshaft to start the fan when the driveshaft was stationary for more than three minutes
3. Using a sensor that switched the fan on when the truck's battery stopped being charged

Option 1 was rejected because the GPS signal would not operate when a vehicle was parked under the deck in a ferry and option 2 was rejected because of the vulnerability of a system that involved using moving parts.

The position of the air-outlet openings: Vents were only positioned in the lower three decks because it was felt that the top deck, that did not have aluminium floors as a ceiling, would have adequate ventilation. It was thought that the air that was being blown into the pen would be at close to ambient temperature and therefore would be lower than the temperature within the front pens when pigs were present. Not only could the incoming air potentially reduce the temperature within the pen but water vapour could be expected to be forced out of the pen through the wall openings.

The air vents were positioned to be in the centre of the pen and at the pigs' head height and airflows were set to the fan's minimum rating. Examination of video footage taken during a large number of journeys showed no evidence that the pigs had any awareness of the air flowing from the ducts and no negative welfare concerns could be detected.

The airflow rate: The ventilation consultant proposed that the air flowing into the pens should be at 50 kph, a rate that would be barely discernable to any animals in the pens but would be sufficient to force air out the nearest wall openings. Since the project was experimental, and there were no guidelines that could be worked to, it was considered that the fan would need to be able to produce variable flow rates that could be adjusted if needed.

The use of an insulation material on the front wall of the stock-crate

As the abattoir had, prior to the study, identified that the majority of the pigs that had died had been transported in the bottom front pen of the truck crate, it was hypothesized that heat from the motor and catalytic converter may have been a contributing factor for the higher death rates in that pen. Some of the heat from the vehicle's motor and catalytic converter could be expected to rise up the gap between the cab and front wall of the stock-crate and potentially heat the front pens via conduction through the crate's aluminium wall.

Graphs 19 and 20 show the changes in temperature and humidity that occurred before and after the installation of the layer of insulation; the data was taken through all four seasons over a two-year period. There was considerable variability within the data with the humidity range recorded by the loggers being up to 45% and the temperature range being up to 17° C. With such a wide variability and the average changes being small, no conclusions could be drawn from the data. However, it would be reasonable to expect that the insulation would have reduced the amount of heat that was being conducted through the aluminium wall. Since any drop in the temperature within the pens would reduce the incidence of heat-stress, it would appear that valuable information could come from further studies that looked at different insulation materials or different thicknesses of the foam that had been used.

Graph 20 illustrates the humidity recorded in the front pens of the stock-crate during the two sets of fifteen journeys. Whilst there appeared to be no difference between the two sets of data, the decrease in humidity recorded on the back wall of the bottom front pen, after the insulation had been put in place, was interesting in that it might suggest that there had been an increase in water vapour movement in that area. This finding suggests that more studies on the effect of insulation could be warranted.

Both before and after the installation of the insulation pigs moved around the bottom front pen at random and did not show any preference for lying beside any of the walls despite temperature differences having been recorded between the side and end walls. It would therefore appear that the primary effect of heat from the walls would be the way in which that heat affected the atmosphere within the pens.

The impact of the fan on the temperature and humidity in the front pens of the stock-crate

A general linear mathematical model was developed to compare the impact that the fan had on the front and back walls of the bottom front pen and the front wall of the pen above it. Using the Tukey Method and a 95% confidence level, the model showed that there was a significant difference in the temperature between the front and back walls, but no significant difference could be shown for either humidity or THI values.

Since the principle behind the use of fans is to disperse water vapour it could be expected that some of the water vapour in the confined space of a pen would have needed to have moved out through the wall openings when air was being forced into the pen by the fan. Any reduction in the water vapour content of the air would have permitted an increase in the ability of the pigs to be cooled by the evaporation of moisture from their skin and thereby their welfare could have been improved.

Graphs 20 and 22 suggest that, despite there being no statistically significant effect on humidity, the fan may have had an effect on the level of humidity in the pen. The data used for the comparisons was collected during summer and winter leading to widely differing temperature ranges (11° C to 27° C) and widely differing humidity ranges (relative humidity ranging from 40% to 88%). If further studies were conducted when the ambient temperature and humidity ranges had less variation, the impact of the fan on humidity might be able to be more clearly defined. Such studies would be important when determining any changes in the fan speed or the on/off pulse sequencing of the fan.

Whilst the data suggests that the fan may have improved the atmospheric environment in the bottom front pen, more studies need to be undertaken to determine whether further improvements are possible.

Wall openings: Norton *et al*. (2013) and Schwartzkopf-Genswein *et al*. (2012) suggested that wall opening design may be important for ventilation. It would appear that if the wall openings were larger than were present in the vehicle used in the current study, more air could be moved in and out of the pens; Randall & Patel, (1994) commented that wall openings should be the full length of the vehicle. Since, unlike the Northern Hemisphere, cold temperatures in the winter months are unlikely to cause significant stress for pigs in New Zealand as indicated by Schrama *et al*. (1996), the use of fans during the winter months could help alleviate the problem of the 'heat-stress' that was recorded during the current study.

In New Zealand more recent wall opening designs have aimed at modifying the shape of the wall openings so that more air would be drawn into the pens when the vehicle was moving (Figure 22, Appendix One). It is proposed that the approach is of concern in that such designs tend to reduce the overall size of the wall openings potentially reducing air exchange during stationary periods. It would appear that further studies directed at measuring the impact of varying wall opening dimensions could be valuable for improving the welfare of stock during road transport.

Managing cold-stress during winter months

The current study showed that cold conditions in the bottom front pen, which caused huddling during winter, only occurred during loading and only lasted for a short period. The heat from the pigs rapidly raised the temperature within the pen so that the pigs soon began to avoid body contact, suggesting that cold-stress conditions were brief.

Frostbite, as has been recorded in the Northern Hemisphere, has not been reported in pigs transported in New Zealand. To accommodate the potential cold-stress problem, it was proposed that the driver could operate the isolator switch that controlled the fan, during loading in very cold weather, only switching the system on at the end of loading or as was perceived to be necessary. Alternatively, a temperature sensor could be added to the control unit that could ensure that the fan did not operate at temperatures below a given point.

Currently conscientious drivers increase stocking densities in very cold weather but it would appear that such a practice might contribute to the DOA/DIY rate that has been recorded during the winter months in New Zealand (Table 14). Increasing the stocking density at the beginning of a journey would lead to increased heat being produced within the pens later in the day when ambient temperatures increase. Since midday winter temperatures can be high (Table 2), the result could lead to significant heat-stress conditions when the vehicle was stationary during winter months; a factor that could explain some of the DOA pigs recorded during the winter.

It would appear to be important that if ‘over-stocking’, as a means to manage cold-stress, is to continue, some form of positive pressure ventilation system should be used to obviate the paradoxical heat-stress that has been shown to occur during the winter months.

CONCLUSION

The use of a positive pressure ventilation system, such as was used in the current study, might resolve the problem of animals in the front pens of stock-crates becoming over-heated during prolonged stationary periods. Further studies need to be undertaken to determine the optimum use of the system and how such a system could be applied to trailers that are used in New Zealand.

SUMMARY

This study indicated that heat-stress-affected pigs are regularly being transported in trucks of a design that is common in New Zealand. Whilst it suggested that the level of transport-related mortality was low by international standards, it was evident that the survivors of the heat-stress occurrences would have had their welfare compromised. That so many of the journeys were affected by heat-stress, would therefore suggest that the road transport systems for pigs in New Zealand should be reviewed.

The videos taken as part of this research reveal that 'market-weight' pigs often rub against the ceilings of the pens when standing in their natural position, this indicating that ceiling heights are inadequate in for-deck stock-crates. The study further suggested that the pens in stock-trucks are probably inadequately ventilated for the transport of these pigs. Whilst regulations do require stock-crate manufacturers to provide for '*adequate*' ventilation within crates, there are no science-based guidelines for the manufacturers, leading to a diversity of wall-opening designs being used in New Zealand.

Taken together, it might therefore be concluded from the study that the design of stock-crates is based primarily on convenience and efficiency for the transport companies, and not to best ensure the welfare of the pigs being transported. What-is-more, it is likely that the public perception of the importance of animal welfare in New Zealand has changed since the vehicle designs were formulated. In concert with the steady increase over the past several decades in the size of livestock species, such as pigs and sheep, ventilation allowances that might have been appropriate at the time of the original designs, could now be ineffective in managing heat-stress in large stock.

The study identified that the loading of the pigs and periods when the loaded vehicle was stationary, were frequently associated with increased heat-stress. To counter this, the welfare of pigs could be improved if more emphasis could be placed on the training of stock-truck drivers about aspects of loading that can lead to stress. Equally, farmers could be encouraged to provide improved loading facilities and management practices that minimise stress before and at loading. Whilst it is inevitable that loaded stock-trucks will experience extended stationary periods, be it for driver comfort stops, while unloading at killing plants, while waiting at ferry terminals and while on ferries, and to be compliant with driver 'hours-of-work' regulations, these can all lead to prolonged stationary periods. In this context, the current regulations appear inadequate to address the animal welfare compromise that might occur during such stationary periods.

Finally, the study demonstrated that a simple positive-pressure ventilation system could be readily applied to the types of vehicle that are currently being used to transport stock in New Zealand. Whilst the use of such ventilation systems may improve conditions within the front pens of a stock-crate, further work would be needed to establish their impact on other pens in the truck's crate and thereby their overall value in improving ventilation.

Overall, this research suggests there is an urgent need for further research into the dimensions of pens and associated wall-openings that would provide adequate ventilation within stock-crates, into transportation practices that would reduce heat stress and into the use of active ventilation systems when loaded trucks are stationary.

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Appendix One

Figure 22: Typical wall opening designs used in New Zealand.

Appendix Two

Regulations and guidelines:

- New Zealand Livestock Transport Assurance programme. June 2013.
- Road Transport Forum NZ. Stock crate code for transportation of livestock, Version 4, November 2004.
- Industry code of practice for the minimisation of stock effluent spillage from trucks on roads. April 2003.
- Standards for transporters transporting pork and bacon weight pigs for slaughter. PQIP, June 1995.
- Code of practice for the manufacture and use of stockcrates on heavy vehicles. NZS 5413:1993
- Canadian Agri-Food Research Council. Recommended code of practice for the care and handling of farm animals. 2001.
- Canadian Food Inspection Agency. Health of animals regulations Part XII(12): Transportation of animals – Regulatory amendment – Interpretive guidance for regulated parties.
- European Commission. Standards for the microclimate inside animal transport road vehicles. 1999.
- European Commission Directive 93/119/EC. Annex A: Requirements for the movement and lairaging of animals in slaughterhouses. Annex B: Restraint of animals before stunning, slaughter or killing.